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ELEMENTARY GEOLOGY

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WITH SPECIAL REFERENCE

TO CANADA

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MCMXXII
LONDON & TORONTO
J. M. DENT & SONS LTD.

PRINTED IN GREAT BRITAIN

PREFACE

So many elementary text-books of Geology are available that it seems almost superfluous to add to the number. Geology, however, is a science embracing, not only general principles of world-wide importance, but the application of those principles to the working-out of the history of a given locality or country.

In this work the general principles of geology are illustrated, as far as possible, by Canadian examples, and the geology of Canada is given especial prominence in the section devoted to Historical Geology.

This method of treatment introduces the student to the subject by reference to localities and geological structures with which he is familiar and lays a local foundation on which the greater geological history of the whole world may be built.

While the book is primarily intended as an introduction to general geology, the emphasis laid on Canadian geological history makes it suitable to those desiring an outline of the geology of Canada. From this point of view, it is hoped that the work will be acceptable to the general reader and to persons engaged in the mining industry in Canada.

Toronto, Ontario.

CHAPTER IV

STRUCTURAL GEOLOGY

PART II.—HISTORICAL GEOLOGY

CHAPTER I

THE MAKING OF THE WORLD

CHAPTER II

THE GENERAL PRINCIPLES OF HISTORICAL GEOLOGY

CHAPTER III

THE NOMENCLATURE AND CLASSIFICATION OF ORGANISMS

CHAPTER IV

THE ARCHÆAN OR PRE-CAMBRIAN

CHAPTER V

THE PALÆOZOIC ERA—THE CAMBRIAN PERIOD

CHAPTER VI

THE ORDOVICIAN PERIOD

CHAPTER VII

THE SILURIAN PERIOD

CHAPTER VIII

THE DEVONIAN PERIOD

CHAPTER IX

THE CARBONIFEROUS PERIOD

CHAPTER X

THE PERMIAN PERIOD

CHAPTER XI

SUMMARY OF THE PALÆOZOIC ERA

CHAPTER XII

THE MESOZOIC ERA—THE TRIASSIC PERIOD

CHAPTER XIII

THE JURASSIC PERIOD

CHAPTER XIV

THE CRETACEOUS PERIOD

CHAPTER XV

SUMMARY OF THE MESOZOIC ERA

CHAPTER XVI

THE CENOZOIC ERA—THE TERTIARY PERIOD

CHAPTER XVII

THE QUATERNARY PERIOD—THE PLEISTOCENE EPOCH

LIST OF ILLUSTRATIONS

ELEMENTARY GEOLOGY

PART I

PHYSICAL GEOLOGY

CHAPTER I

INTRODUCTORY

THE earth is man's home, his workshop, his storehouse, his playground, the environment which shapes him to what he is; and every intelligent man should know something of it, particularly in regard to his immediate surroundings and his own country.

The earth is only a modest planet in a solar system of quite moderate dimensions, as solar systems go in the universe; but it is the only planet we can ever know at all intimately, and small as it is, it is full of interest, and has a thrilling history that accounts for all about us and even for the race of man himself. No one is really educated in the modern sense who does not know something of the solid ground beneath his feet and of the shaping of the hills and valleys and plains among which he lives. His house, his tools and instruments, and even his tableware are usually made of materials drawn from the earth and therefore taken from the realm of geology. He cannot walk the streets of a city without seeing everywhere things that have a geological origin; and when he tills the soil or makes the bricks of everyday life he is handling geological materials and doing geological work, whether he knows it or not.

Whether from the economic or the intellectual side, in war or in peace, man is perpetually confronting geological factors that are of vital importance to him, and of which he cannot be ignorant without loss of efficiency and loss of a mental stimulus.

Geology is the science of the earth, and the earth is many sided, so that it has, perhaps, the widest affiliations of any of the sciences and is itself almost a bundle of sciences, there are so many avenues along which its researches may be directed. On this account geologists by profession are bound to specialise, since no one man can be equally proficient in all departments of so protean a subject.

SUBDIVISIONS OF GEOLOGY

Geology deals with the materials of which the earth is made, the forces that operate upon them, the structures which result from this operation, the distribution of the rocks forming the earth's crust, and the history of the earth itself and of the plants and animals which have inhabited it during the different ages.

The usual divisions of geology as treated in a text-book are as follows:

Lithology. The study of rocks and of the minerals of which they are composed.

Dynamic Geology. A consideration of the forces which have shaped and still are shaping the earth.

Structural Geology. Dealing with the architecture of the earth's crust.

Historical and Stratigraphical Geology. Showing the order and distribution of the different series of rocks, and unravelling the history of the earth and its inhabitants as disclosed in the rocks.

Lithology draws on the cognate science of mineralogy for aid; Dynamic Geology makes use mainly of the principles of physics and chemistry, but touches also zoology and botany; Structural Geology deals with the attitude and arrangement of rocks; and Historical Geology derives much aid from palæontology, the science which deals with fossils. Historical Geology may be said to begin with astronomy and to end with physiography, or physical geography, which deals with the present surface features of the earth.

THE EARTH AS A WHOLE

The earth is one of the minor planets of the solar system, with a diameter of almost 8000 miles. It is often called a globe or sphere, but not quite correctly, since it is flattened at the poles. It approaches the form of a rotating mass of fluid, which would be called an "oblate spheroid" or an "ellipsoid of rotation," but does not quite attain perfection, since its surface has irregularities, elevations, and depressions, with extremes amounting to eleven miles, and its equatorial circumference is not exactly a circle. The polar diameter is given as 7925·6 miles and the average equatorial diameter as 7899·1, the polar flattening representing half the difference, or a little over thirteen miles.

THE EARTH'S MOTIONS

The planetary motions of the earth, its annual revolution about the sun and its diurnal rotation about its axis, are of great importance as influencing tides, currents, winds, and climates; and the fact that the earth's axis is inclined 23·5 degrees to the plane of its orbit is also a matter of interest. A change in any of these relations would have serious effects. There is reason to believe that tidal friction is very gradually slowing down the energy of rotation, and it has been suggested that in early times the earth rotated in six hours instead of twenty-four. Such a difference would greatly alter the shape of the earth, increasing the equatorial bulge and shortening the polar diameter. There is no doubt that any variation in the shape of the earth due to the lengthening of the day, as suggested, would result in bucklings of the crust such as would make mountain ranges and depressions in the sea bottom. A more rapid rotation would speed up a number of terrestrial activities such as tides and winds, and make them more effective geological agencies.

A change in the inclination of the earth's axis would profoundly affect geology. If the axis stood at right angles to the plane of the earth's orbit, there would be no alternation of seasons, with all which that implies; and other conceivable

arrangements might have tremendous effects. Some geologists have suggested a change in position of the poles to account for the occurrence of ice ages, times when great ice sheets covered parts of the temperate zones and even advanced into the tropics, but there is a serious difficulty in the way of such a change. The rotating earth is a gyroscope on a huge scale and would violently resist any shifting in the direction of its axis of rotation, so that a sudden variation of the sort would probably tear the earth to pieces.

The geological record does not indicate any remarkable or rapid change in the earth's motions, and, in fact, shows a surprising uniformity in its relations to the other members of the solar system. There is no evidence, for instance, of greater tidal activity in the earliest water-formed rocks; and there is no proof that the sun radiated more heat to the earth a hundred million years ago than it does now; for liquid water and great sheets of ice were at work then as now.

THE COMPOSITION OF THE EARTH

So far as we know the earth's composition by direct study it is formed of various rocks, which will be described later, such as granite or limestone or sandstone. The average specific gravity of these rocks is 2·6 or 2·7, and the heaviest rocks known to occur on a large scale do not much exceed 3 in specific gravity; yet the earth as a whole has a specific gravity of 5·5 or 5·6—nearly double as much. Evidently the materials below the surface are much heavier than those within our reach: this has been explained by supposing that the central parts consist of heavier elements, such as iron and nickel, which occur only in relatively small amounts in the earth's crust, the only part which we can examine. It has been suggested, however, that the same materials as make up the crust might be greatly compressed by the weight of the overlying rocks, and so attain a higher specific gravity. Perhaps a combination of the two theories is best.

Since the earth, as known to us, consists of rock, it may be called the "lithosphere," from the Greek word for rock; but we can actually examine only a little more than one-fourth of its

surface, the rest being beneath the sea. The incomplete spherical covering of water may be called the "hydrosphere." Above all rises a sea of air, reaching indefinitely upwards, which is, of course, the "atmosphere." Geology is largely occupied in studying the interactions of the atmosphere and hydrosphere upon the lithosphere. Beneath the lithosphere some geologists place an "asthenosphere" (strengthless) capable of flow like a plastic body, while the unknown interior may be called the "centrosphere."

Of the many known chemical elements comparatively few play any important part in building the earth's crust, and there seems to have been a strange partiality shown for eight of them—oxygen, silicon, aluminium, iron, calcium, magnesium, sodium, and potassium—which make up ninety-eight per cent. of the rocks examined, oxygen alone forming fifty per cent. Carbon, one of the most important substances in practical life, forms less than one-fifth of one per cent. of the rocks available to man; and copper, lead, zinc, and the other economic metals, leaving out iron, provide only minute fractions of one per cent. It may be that the balance is restored in the earth's interior, the heavier elements gravitating towards the centre.

Of the chemical compounds, silica, a compound of silicon and oxygen, outweighs the others put together and enters largely into the composition of many rocks.

CHAPTER II

MINERALS AND ROCKS [1]

THE geological history of the earth is recorded in the rocks. It is obvious that the nature of the rocks, and the chemical and physical changes which they have undergone, will contribute in no small degree to the main object in view—the working out of the history of the earth.

MINERALS

All matter is made up of certain primary substances known as *elements*, of which only a few occur as such in the make-up of the earth. Gold, silver, copper, and arsenic are among the elements that are found in the rocks; when so found they are called *native* gold, silver, copper, etc. On the other hand, iron, which is a very common element, occurs with extreme rarity as native iron. Most of the elements never occur native but united with one another to form chemical compounds. These compounds are made up of very definite amounts of the elements composing them, and they differ entirely from any of the constituent elements. For instance, water is made up of two colourless gases, oxygen and hydrogen, united in the proportion of eight to one; and most of the iron of commerce is made from a red or black brittle substance composed of iron and a definite proportion of this same colourless gas, oxygen. Commercial iron is made by subjecting this substance to furnace operations whereby it is forced to let go the oxygen which it contains. If a piece of iron is allowed to lie out in the weather it slowly rusts and eventually crumbles away to a reddish powder. Nature has claimed her own again, and the man-made iron has gone back again into the union with oxygen which is natural to it. Processes of this kind have been going on in nature's workshop throughout the geological ages, with the net result that the earth, as far as we know it,

[1] A proper conception of minerals and rocks can be acquired only by seeing and handling specimens. The few minerals and rocks herein described are treated in the merest outline only. The student is advised to consult any of the standard works on mineralogy and petrography.

is made up of a small amount of native elements and a great amount of chemical compounds. Both of these are *minerals*, and that branch of geological science which deals with them is *mineralogy*.

It is evident that the chemical composition of a mineral is a matter of the first importance, and without at least an elementary knowledge of chemistry it is difficult to properly understand minerals. Fortunately, however, minerals are possessed of very characteristic *physical* properties, whereby they may be easily recognised even by one to whom their chemical nature is entirely unknown. A student need not despair of acquiring a fair knowledge of minerals even if his acquaintance with chemistry is limited. In the brief descriptions of minerals given herein only a knowledge of the names of the elements, and of such common substances as silica, alumina, lime, and magnesia is presupposed on the part of the reader.

The chief physical properties made use of for the description and identification of minerals are as follows:

LUSTRE. Some minerals have the appearance of metal and are said to have a *metallic* lustre; others, such as a piece of common limestone, have no resemblance to a metal and are said to have a *non-metallic* lustre. These are the two chief lustres; others of less importance are *pearly*, *vitreous*, *resinous*, *silky*, and *earthy*—terms which sufficiently explain themselves.

COLOUR. The actual colour of a mineral is important, particularly when combined with metallic lustre.

STREAK. The streak is the colour of the finely powdered mineral and is often different from that of the mineral itself. This property is very constant and is of more value than colour in the case of minerals with non-metallic lustre. The streak may be obtained by crushing a small piece of the mineral or by drawing a fine file across it.

HARDNESS. This property is of great value. In order to express it in short form a scale has been established using the numerals 1 to 10 to indicate increasing degrees of hardness. A mineral with the hardness 1 can be scratched by the thumb nail; 3 is about equal to copper; 5 scratches glass feebly; 6 scratches glass easily; 7 is quartz or rock crystal which is much harder than glass; 8, 9, and 10 are harder than quartz.

WEIGHT. The weight, or more properly the *specific gravity*,

of a mineral is fairly constant. Common rock-making minerals vary from 2·5 to 3 or a little more. The ores of the metals are heavier; they average about 6 or 7, but in some cases run considerably higher—for instance, native gold has a specific gravity of 19·5.

CRYSTAL FORM. Nearly all minerals assume a definite shape

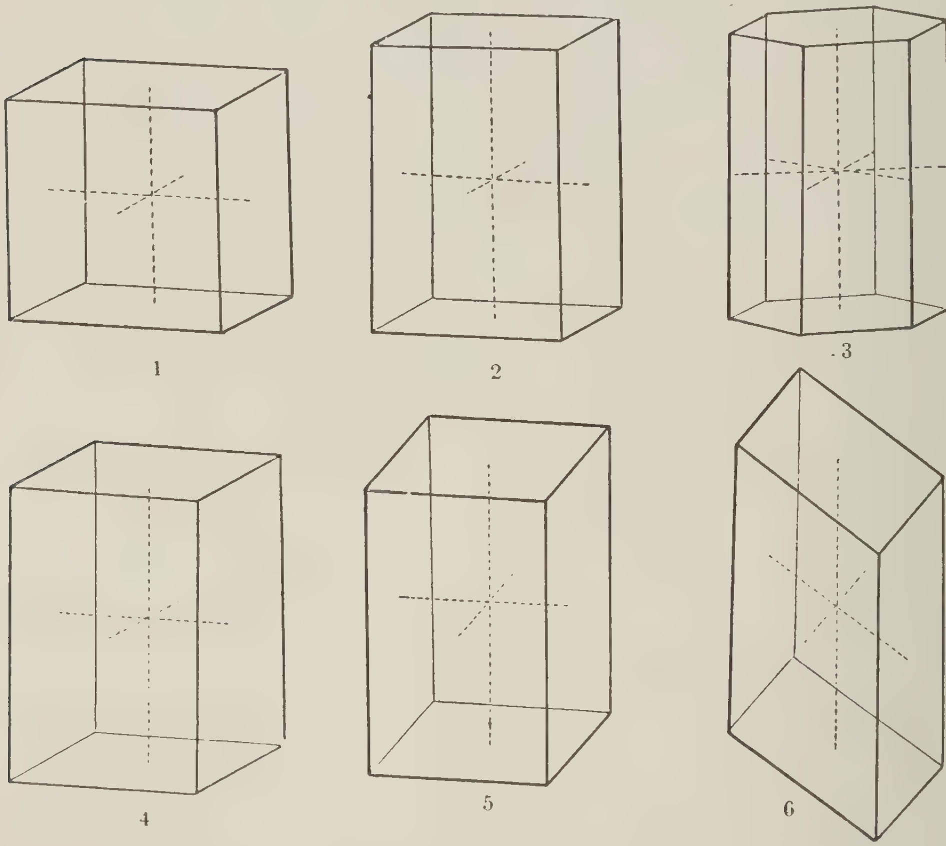

FIG. I. GROUND FIGURES OF THE SIX SYSTEMS OF CRYSTALS

By modifications of these forms, the replacement of angles and edges by other planes, all known crystals may be derived.

which is extremely characteristic and which in most cases would suffice for their determination in the hands of an expert. Unfortunately, when minerals occur in masses the crystals are so closely pressed together that their form is obscured, but never altered. Crystals are bounded by flat planes which meet each other in angles of absolute constancy. Several systems of crystals are recognised depending on the degree of symmetry they present. In some the planes are arranged regularly about a centre (cubic or regular system);

in others in a tetrameral manner about a long axis (tetragonal system); in others in a hexagonal manner about a long axis (hexagonal system); in others about three axes of different lengths set at right angles to one another (rhombic system); in others about three unequal axes of which only two are at right angles (monoclinic system); and finally about three unequal axes none of which is at right angles to another (triclinic system).

CLEAVAGE. Many crystals have a tendency to split parallel to certain planes. Even when the form cannot be made out this property is useful in determining minerals as it is very constant.

From 1200 to 1500 minerals in all are known to science; of these a comparatively small number compose the great bulk of the earth's crust. The commonest minerals are those which are aggregated together to make up rocks, and are known as rock-forming minerals. In smaller amount occur the minerals which are used as ores of the metals. Other minerals worthy of mention in a work of this kind are those which are used for the production of useful substances of a non-metallic nature. The remaining minerals are of little importance from the present point of view. The more common minerals will be briefly considered in groups as below:

I. COMMON MINERALS FORMING IGNEOUS ROCKS

QUARTZ. This is the commonest of all minerals and makes up a large part of the rocks of the earth: it is composed of silica, a compound of the elements silicon and oxygen.

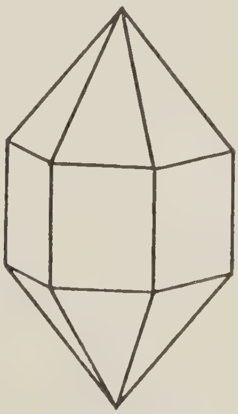

FIG. 2. CRYSTAL OF QUARTZ

Quartz forms six-sided prisms with a six-sided pyramid on each end; therefore, it is said to crystallise in the hexagonal system. There is no cleavage as the mineral breaks irregularly. The lustre is non-metallic and vitreous; normally colourless and transparent, quartz is frequently tinged by the presence of foreign matter. The streak is colourless; the hardness 7; and the specific gravity about 2·65.

Quartz is a constituent of granite and of many other

igneous rocks; it also makes up a large part of most sandstones. The *gangue* or vein-filling material of the gold mines of northern Ontario is quartz, and the coloured variety known as amethyst is obtained along the Fundy shore of Nova Scotia and the north shore of Lake Superior.

FELDSPARS. This group of minerals comprises several related chemical compounds of silica and alumina with potash, soda, and lime. A number of minerals are included, but they may be divided into two classes: (1) orthoclase or potash feldspar, and (2) plagioclase or soda-lime feldspar. The physical properties are much alike in all the feldspars: the lustre is non-metallic; the colour variable, but usually light—white, pink, bluish, etc.; the streak colourless; the hardness 6; and the specific gravity 2·4 to 2·7.

FIG. 3. CRYSTAL OF ORTHOCLASE FELDSPAR

The two kinds of feldspar differ slightly in their crystal form; orthoclase is monoclinic and plagioclase triclinic. Both varieties have distinct cleavage, a property which is of great use in distinguishing them from quartz which has no cleavage. The character of the cleavage is also of great use in distinguishing between the two kinds of feldspar, as in the case of orthoclase it is smooth, whereas the cleavage faces of plagioclase show fine parallel striations.

Feldspar of one kind or the other is a constituent of nearly all the igneous rocks, the classification of which depends very largely on the kind of feldspar present. One must remember that the distinction between the two kinds of feldspar is of prime importance and not merely a matter of detail.

Feldspar is used in the ceramic arts to a large extent, also in metallurgical operations, and for many specific purposes. Orthoclase is a possible source of potash, but its separation is a matter of difficulty not yet achieved on a commercial scale. Large feldspar mines are worked to the north of Kingston in Ontario.

NEPHELINE. This mineral is related in composition to the feldspars, but it crystallises in the hexagonal system. Nepheline is a constituent of igneous rocks of much rarer occurrence

than feldspar; its mention here is justified by its presence in important masses of rock in Ontario.

PYROXENE. This mineral is a complicated compound of silica with lime, magnesia, iron, manganese, and other substances; alumina also is present in many varieties. The crystals are of the monoclinic type and have a pronounced cleavage parallel to two planes which meet at an angle of 87° 5′; this property is of great value as a means of determination, as broken pieces of pyroxene will be sure to present fragments on which this angle may be observed.

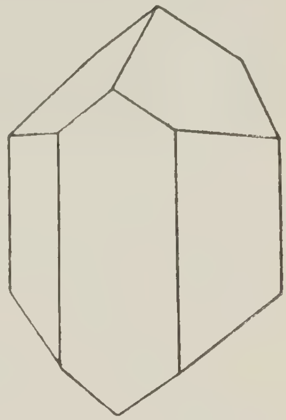
FIG. 4. CRYSTAL OF PYROXENE

The lustre is non-metallic and rather vitreous; the colour varies from light green to black; streak colourless or light greyish green; hardness 5 to 6; specific gravity 3·23 to 3·5, indicating a heavier mineral than quartz or feldspar.

Pyroxene is a very common rock-forming mineral and is particularly abundant in the dark-coloured, heavy igneous rocks. Many varieties are known, such as *augite* and *diallage*. *Hypersthene* is a mineral related to pyroxene in composition, but crystallising in the rhombic system; it is sometimes called *rhombic pyroxene*. The common pyroxene, augite, is most likely to be mistaken for hornblende, but it may easily be distinguished by the angle of cleavage.

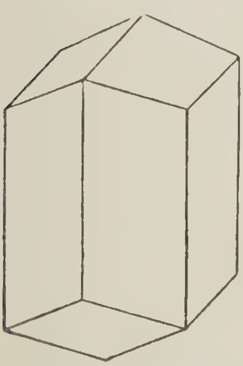
FIG. 5. CRYSTAL OF HORNBLENDE

HORNBLENDE. The chemical composition of this mineral is very similar to that of pyroxene; its crystal form also is similar, but differs in the important respect that the cleavage angle is 124° 30′ instead of 87° 5′ as in pyroxene. This difference of angle may usually be relied on to distinguish between the two minerals. The other physical properties are practically the same as those of pyroxene.

Hornblende is a common constituent of the igneous rocks, but it is less common than pyroxene in the very dark rocks; on the other hand, it is more frequent in the intermediate and light-coloured rocks.

Mica Group. This group contains a number of complicated compounds of silica, alumina, lime, magnesia, potash, and other substances in less amount. While the crystal forms belong to different systems in the different micas they all approximate to six-sided prisms and they all have a very strong tendency to cleave across the prism, whereby the familiar sheets of mica are broken off.

The lustre is sometimes sub-metallic, pearly, or even vitreous; the colour varies with the varieties, from clear transparent to almost black; the streak is colourless or very lightly tinted; the hardness seldom exceeds 3; the specific gravity is usually between 2·7 and 3·1.

Many varieties based on different chemical composition and slightly different physical properties are known: the chief of these are *biotite* or black mica with much iron and magnesia, *muscovite* or white mica with much potash, and *phlogopite* or amber mica with magnesia and potash.

Mica is a very common constituent of rocks; when black, it may be mistaken in a rock for pyroxene or hornblende, but it may be distinguished by picking with a needle which will cause the thin, characteristic flakes to exfoliate.

Olivine. This mineral is a compound of silica with iron and magnesia; it forms crystals of the rhombic type. The physical properties are very similar to those of pyroxene and hornblende. The colour is greenish and generally lighter than in these two minerals, and the absence of the characteristic cleavage is of value as a means of determination.

Olivine occurs more particularly in the very dark-coloured igneous rocks.

II. NON-ESSENTIAL AND SECONDARY MINERALS OF IGNEOUS ROCKS

The great mass of igneous rocks is made up of the minerals given above; other important minerals occur in less amount as well as some which may or may not be present in a given rock and, therefore, are *non-essential*. As a result of decay and alteration new minerals may be formed: these are usually called *secondary*.

The commonest non-essential and secondary minerals of igneous rocks are:

Garnet Group. Garnets are compounds of silica with alumina, iron, lime, and sometimes with manganese, chromium, etc. They form crystals of the regular or cubic type which are often symmetrically twelve-sided forms, each face being a rhombus.

The lustre is vitreous to resinous; the colour varies with the composition, usually being reddish or brownish, but sometimes green; the streak is colourless; the hardness is 6·5 to 7·5; and the specific gravity 3·15 to 4·3.

Garnet is more common in metamorphic than in igneous rocks. Common varieties are useful as abrasives on account of their hardness and toughness; clear and pure varieties, particularly the red *pyrope*, are used as gem stones.

Chlorite. This mineral occurs only as the result of the decay of other minerals such as augite, hornblende, and mica. It is of complicated composition, soft, and greenish in colour. Chlorite belongs more properly to the metamorphic rocks, but it may occur in igneous rocks which are but little altered.

In addition to the above minerals a long list might be made of the non-essential minerals of the igneous rocks. Some of these will be described under different heads, *e.g.*, magnetite, hematite, pyrite, and apatite.

III. ADDITIONAL MINERALS OF THE METAMORPHIC ROCKS

Igneous rocks which have been subjected to extreme alteration frequently contain minerals not present before the changes were effected. Chlorite and garnet, already mentioned, are among the commonest of these, and in addition are the following:

Serpentine. This mineral is essentially a compound of silica, magnesia, and water. It is questionable if it has a crystal form of its own as it always occurs as an alteration of hornblende, pyroxene, olivine, etc.

The lustre is resinous to greasy; the colour generally greenish to yellowish green; the streak colourless; the hardness variable but generally low, about 2·5 to 4; the specific gravity 2·5 to 2·65.

The dark-coloured igneous rocks, particularly those made

up of a large percentage of olivine, are liable to be altered *en masse* into serpentine. Sometimes this massive serpentine is of value as decorative stone, as in the Gaspé peninsula and in the eastern townships of Quebec.

Serpentine sometimes assumes a delicately fibrous form known as *chrysotile* which is commonly called *asbestos*. The fire-resisting properties of this material and its capability of being woven into fireproof fabric give it a high value. The mining of asbestos is one of the unique industries of Canada; it centres chiefly about Black Lake in the eastern townships of Quebec.

Talc. This is another compound of silica, magnesia, and water which results from the alteration of minerals like hornblende, pyroxene, and olivine. When pure the lustre is pearly, the colour white or greenish, and the streak colourless. It is one of the softest minerals known, as the hardness ranges from less than 1 to 1·5.

Clean, well-crystallised talc is not common and is of value for the manufacture of toilet powders, for which purpose it is extensively mined near Madoc in Ontario. Impure massive forms of talc are known as soapstone and are used for various industrial purposes.

Sillimanite. Essentially a compound of silica and alumina. It forms long slender crystals which in extreme cases are fibrous. The lustre is non-metallic; the colour brown, grey, or green; the streak uncoloured; the hardness 6 to 7; and the specific gravity 3·2 to 3·3.

This mineral would scarcely be mentioned were it not for its presence in rocks of frequent occurrence in northern Canada.

Epidote. This mineral is a complicated compound of silica, alumina, iron, and lime with a small amount of water; it occurs in both igneous and metamorphic rocks. The crystal form is monoclinic.

The lustre is vitreous to pearly and resinous; the colour usually yellowish green; the streak uncoloured; the hardness 6 to 7; and the specific gravity 3·25 to 3·5.

Sericite. This mineral is related to the micas, but it contains more water than the typical micas already mentioned. It occurs in the form of silvery, glistening scales in schistose rocks and is always the result of alteration of original minerals.

IV. MINERALS OF THE SEDIMENTARY ROCKS

Rocks which have been laid down in water may contain fragments of any of the minerals of the igneous rocks; in addition are the following:

Calcite. Carbonic acid gas is a constituent of the atmosphere; it is a compound of oxygen and carbon and is formed when fuel is burned either in the ordinary way or in the lungs of animals. This gas is always ready to enter into combination with lime, as may be proved by blowing air from the lungs into lime water. On performing this simple experiment one will immediately see a white powder formed which settles to the bottom of the vessel. This white powder is *carbonate of lime.* The same substance occurring under natural conditions where it has a chance to crystallise is the mineral *calcite.*

Crystals of calcite are usually six-sided prisms with pointed ends; frequently also, especially in rocks, the form is that of a rhombohedron. Whatever the shape of the crystal the cleavage is rhombohedral, a property which is well developed and constantly present.

The lustre is non-metallic, vitreous to earthy; the colour is normally clear transparent, but opaque white and various lightly coloured varieties are known; streak colourless; hardness 2·5 to 3·5; specific gravity about 2·7.

Pure limestone is composed entirely of carbonate of lime, probably in the form of calcite. Marble is distinctly crystalline limestone, and therefore is certainly made up of the mineral calcite. Calcite is of frequent occurrence in mineral veins and is often the result of decay in lime-bearing minerals of the igneous rocks.

Carbonate of lime sometimes crystallises in a form different from that of calcite; it is then known as *aragonite,* which is a distinct mineral although of the same composition as calcite.

Magnesite. Just as calcite is the carbonate of lime, magnesite is the carbonate of magnesia. The physical properties are somewhat similar, but magnesite is heavier, having a specific gravity usually exceeding 3. This mineral is included here on account of its close relationship to calcite rather than

to its occurrence in stratified rocks; its more usual occurrence is as an alteration product in connection with serpentine.

Dolomite. This mineral is a carbonate of lime and magnesia; it is intermediate between calcite and magnesite, and has physical properties in accord with that position. The significance of this mineral will be more fully appreciated when the description of the sedimentary rocks has been read.

Kaolinite. This is a very important mineral composed of silica, alumina, and water. The form of the crystal is doubtful as the mineral usually occurs as tiny pearly scales. The lustre is non-metallic pearly; the colour is normally white, but various light tints may be shown; streak uncoloured; hardness 1 to 2·5; specific gravity about 2·5.

Kaolinite results from the decay of orthoclase. Together with other related minerals it makes up the bulk of clay beds and is responsible for the plastic properties of clay.

V. MINERALS USED AS ORES OF THE METALS

Gold is found chiefly in the native state, but it also occurs as a constituent of a few rare minerals. The metal is also obtained from the ores of copper and other metals in which it occurs in small quantities.

Native Gold. Gold crystallises in the regular system usually in the form of octahedrons. The lustre is metallic; colour and streak yellow; hardness 2·5 to 3; specific gravity 15·6 to 19·5; malleable.

Silver occurs native and in combination with other substances in a number of minerals. Much silver is produced also from lead ores in which silver takes the place of part of the lead.

Native Silver. The crystals belong to the cubic system, but generally they are aggregated into dendritic masses. The lustre is metallic; the colour and streak silver white; hardness 2·5 to 3; specific gravity 10·1 to 11·1; malleable.

Argentite. This mineral is a compound of silver and sulphur which crystallises in the cubic system. Lustre metallic; colour and streak blackish lead-grey; hardness 2 to 2·5; specific gravity about 7·3; somewhat malleable.

Copper occurs native and also in combination with other

elements in a large number of minerals. The chief ores are as follows:

Native Copper. Crystallisation cubic, but generally shows dendritic aggregations; lustre metallic; colour copper-red; streak metallic shining; hardness 2·5 to 3; specific gravity 8·8; malleable.

Chalcopyrite. Also called *copper pyrites.* This mineral is a compound of copper, iron, and sulphur; crystals tetragonal; lustre metallic; colour brass-yellow; streak greenish black; hardness 3·5 to 4; specific gravity 4·1 to 4·3; brittle.

Bornite. Also called *purple copper ore.* Bornite is a compound of copper, iron, and sulphur differing in proportion from that of chalcopyrite; it crystallises in the cubic system. The lustre is metallic; the colour between red and brown; streak greyish black; hardness 3; specific gravity 4·4 to 5·5; brittle.

Chalcocite. Also known as *copper glance.* This mineral is a compound of copper and sulphur; its crystals belong to the rhombic system. The lustre is metallic; the colour and streak blackish lead-grey; hardness 2·5 to 3; specific gravity 5·5 to 5·8; brittle.

Malachite. A carbonate of copper with water; crystals monoclinic. The lustre is adamantine to vitreous; the colour bright green; streak paler green; hardness 3·5 to 4; specific gravity 3·7 to 4·01.

In addition to being used as an ore of copper, malachite is a very handsome decorative material.

Iron in the native condition is very rare. The important minerals are the oxides and carbonates of iron.

Hematite. Sometimes called *red iron ore.* A compound of iron and oxygen with 70 per cent. iron; crystals hexagonal; lustre metallic; colour dark steel-grey; streak red to brown; hardness 5·5 to 6·5; specific gravity 4·5 to 5·3; brittle.

Magnetite. Also known as *magnetic iron ore.* A compound of iron and oxygen with 72·4 per cent. iron; crystals cubic, generally octahedra; lustre metallic; colour and streak black; hardness 5·5 to 6·5; specific gravity 4·9 to 5·2; brittle; magnetic. The colour of the streak and the property of magnetism suffice to distinguish this mineral from hematite.

Limonite. Known also as *brown iron ore.* A compound of

iron, oxygen, and water; no crystallisation; lustre sub-metallic, silky; colour brown; streak yellowish brown; hardness 5 to 5·5; specific gravity 3·6 to 4; brittle.

SIDERITE. A compound of iron and carbonic acid; crystallises in rhombohedrons of the hexagonal system; lustre non-metallic; colour variable, but usually ash-grey to brownish; streak uncoloured; hardness 3·5 to 4·5; specific gravity 3·7 to 3·9; brittle.

The chief ore of lead and the only one to be considered here is galena, which is also important as a source of silver, as the lead is frequently replaced in part by silver.

GALENA. A compound of lead and sulphur with 86·6 per cent. lead. Crystals cubic; cleavage cubic; lustre metallic; colour and streak lead-grey; hardness 2·5 to 2·75; specific gravity 7·25 to 7·7; brittle.

Zinc is obtained from various minerals, chiefly the sulphide, carbonate, and silicate; the first mentioned is much the most important and will alone be considered.

SPHALERITE. Also known as *zinc blende*. A compound of zinc and sulphur with 67 per cent. zinc; crystals cubic with pronounced cleavage; lustre resinous; colour variable, brown, yellow, black, red, green, commonly amber-coloured; streak white to light reddish brown; hardness 3·5 to 4; specific gravity 3·9 to 4·2; brittle.

Cobalt occurs in a number of rather rare minerals. On account of its abundance in the silver region of Cobalt in Ontario, we may regard smaltite as the most important.

SMALTITE. A compound of cobalt and arsenic with usually a small amount of iron and nickel; crystals cubic; lustre metallic; colour tin-white to steel-grey; streak greyish black; hardness 5·5 to 6; specific gravity 6·4 to 7·2; brittle.

Nickel occurs in several minerals, the chief of which are compounds of nickel with sulphur, arsenic, or antimony. Nevertheless, most of the nickel from the famous mines at Sudbury, Ontario, is obtained from a compound of iron and sulphur known as *pyrrhotite* which is mixed with a nickeliferous mineral, *pentlandite*. Visible pentlandite is of rather

rare occurrence in these ores, consequently the more common mineral pyrrhotite will be described.

PYRRHOTITE. A compound of iron and sulphur; crystals hexagonal, rare; lustre metallic; colour bronze-yellow to copper-red; streak dark greenish black; hardness 3·5 to 4·5; specific gravity 4·4 to 4·68; brittle.

This mineral somewhat resembles another compound of iron and sulphur, *pyrite*, but it may be distinguished by its inferior hardness and the difference in colour and streak.

Arsenic occurs as native arsenic and in combination with many of the metals. Most of the arsenic of commerce is produced as a by-product in treating ores for other metals.

ARSENOPYRITE, ARSENICAL PYRITES, OR MISPICKEL. A compound of iron arsenic and sulphur with 46 per cent. arsenic; crystals rhombic; lustre metallic; colour silver-white to steel-grey; streak dark greyish black; hardness 5·5 to 6; specific gravity 6 to 6·4; brittle.

Antimony occurs native and in combination with many metals; the chief ore is stibnite.

STIBNITE. This mineral, also known as *antimony glance*, is a compound of antimony and sulphur with 71·8 per cent. antimony. The crystals belong to the rhombic system and are often very elongated; lustre metallic; colour and streak lead-grey; hardness 2; specific gravity 4·5; sectile.

Tin is obtained almost entirely from one mineral, cassiterite.

CASSITERITE OR TIN STONE. A compound of tin and oxygen. The crystals are frequently well formed and belong to the tetragonal system; lustre non-metallic, adamantine; colour usually brown to black, but sometimes even white; streak colourless, greyish, brownish; hardness 6·7; specific gravity 6·4 to 7·1; brittle.

VI. OTHER MINERALS OF ECONOMIC IMPORTANCE

GYPSUM. A compound of lime, sulphuric acid, and water; it is sulphate of calcium with 20·9 per cent. water. The crystals are frequently well formed and belong to the monoclinic system; the cleavage is well marked; lustre non-metallic, pearly, shiny, sub-vitreous; colour normally white, sometimes

greyish, reddish, etc.; streak white; hardness 1·5 to 2; specific gravity 2·3.

Pure, well-crystallised gypsum is colourless and transparent; it is known as *selenite.* Massive, granular, scaly, and other varieties are known. Plaster of Paris is manufactured by heating gypsum until most of the water is expelled. The setting of the plaster is due to the taking up of water and the re-formation of crystallised gypsum. As gypsum occurs chiefly in beds with other stratified rocks it might well be considered as one of the minerals of the stratified rocks.

Halite or Common Salt. A compound of sodium and chlorine. Crystals cubic with good cubic cleavage; lustre vitreous; colour usually white, but may be reddish, greyish, etc.; streak white; hardness 2·5; specific gravity 2·1; brittle; soluble in water; saline taste. Like gypsum, rock salt may be considered as one of the minerals of the stratified rocks.

Corundum. A compound of aluminium and oxygen, *i.e.* alumina. The crystals belong to the hexagonal system and are frequently well formed; lustre non-metallic, vitreous; colour extremely variable, white, red, blue, brown, yellow; streak colourless; hardness very high, 9; specific gravity 4; brittle.

On account of its hardness corundum is a valuable abrasive. The impure black variety is *emery*. Some of the most valuable jewels are corundum; for instance, the oriental ruby is red corundum, and the oriental sapphire is blue corundum.

Graphite. This mineral is carbon in the form which is commonly known as blacklead. Lustre metallic; colour and streak black; hardness 1 to 2; specific gravity 2·2; sectile; marks paper.

Graphite is used for making black paint and stove polish, for lead pencils and crucibles; it also finds many other applications in the industrial arts. Occurrences of graphite are common in eastern Ontario and in Quebec north of the Ottawa river.

Pyrite. A compound of iron and sulphur with 53·3 per cent. sulphur. The crystals are cubes or modified cubes; lustre metallic; colour pale brass-yellow; streak greenish or brownish black; hardness 6 to 6·5; specific gravity 4·8 to 5·2; brittle. Pyrite is a very common mineral; it occurs in veins,

as an accessory constituent in igneous rocks, also in metamorphic and sedimentary rocks.

The chief use of pyrite is for the manufacture of sulphuric acid: it is not commonly employed for making iron as the entire separation of the sulphur is too difficult. Pyrite frequently carries small amounts of gold, in which case it is used as an ore of that metal. The resemblance of pyrite to gold has led to the popular name "fool's gold."

Apatite. A compound of lime, phosphoric acid, and fluorine. Crystals hexagonal, often with well-developed six-sided prisms; lustre vitreous to resinous; colour usually greenish, sometimes reddish or otherwise tinted; streak colourless; hardness 5; specific gravity about 3; brittle.

This mineral is important as a source of phosphorus and phosphoric acid; it occurs in eastern Ontario and in Quebec north of the Ottawa river.

Agate. Water containing silica in solution sometimes deposits that substance on the walls of cavities in certain of the igneous rocks. Eventually the cavity is wholly or partially filled with silica arranged in a concentric manner and presenting delicate and varying shades of colour. Silica in this form is known as *agate*.

Jasper. This mineral is also a form of silica to which a bright red colour is given by the presence of oxide of iron.

Chromite. Also known as *chromic iron ore*. A compound of iron, chromium, and oxygen. Crystals cubic system; lustre sub-metallic; colour iron-black or brownish black; streak brown; hardness 5·5; specific gravity about 4·4; brittle.

Chromite is smelted with iron ores to produce an alloy of chromium and iron; the mineral, therefore, might be considered as an ore of these metals. A great amount of chromite is used for making various chemical compounds much employed in the industrial arts.

ROCKS

Rocks are masses of mineral matter of sufficient size and importance to form essential elements in the building up of the earth's crust: they are to be distinguished from those smaller, less frequent, and non-essential occurrences of mineral

matter, such as the filling of veins and cavities. Rocks are composed of mineral matter, but not always of definite minerals. Sometimes a rock is made up of one mineral only, as in the case of pure marble which is composed entirely of the mineral calcite; or in the case of anorthosite made up entirely of the mineral feldspar. Other rocks are composed of several minerals; for instance, the rock granite is made up of the minerals quartz, feldspar, and mica. Rocks such as sandstone are not made of definite minerals, but of broken pieces of minerals derived from the decay of earlier rocks and cemented together by a foreign substance; such rocks are termed *fragmental* or *clastic*.

The broadest classification of rocks is based on their mode of origin as follows:

1. *Igneous rocks.* The result of the solidification of molten matter.
2. *Sedimentary rocks.* Built up of mineral matter derived from earlier rocks and deposited in layers, usually by water but sometimes by air.
3. *Metamorphic rocks.* Rocks of either of the above classes which have been so altered by natural processes that their original nature is greatly changed.

IGNEOUS ROCKS

Molten matter from the interior of the earth may be poured out on the surface, or it may rise into fissures and consolidate before escaping, or it may cool at great depths in the earth and not be visible until the overlying rocks have been worn away by erosion. The nature of the resulting igneous rock depends in part on the manner of cooling as above indicated, and in part on the original chemical composition of the molten matter. The manner of cooling expresses itself in the *structure* of the rock, and the original chemical composition is indicated by the *minerals* which form in the process of cooling. All igneous rocks, therefore, have to be examined from two points of view—the structure and the mineral composition.

If a molten mass is poured out on the surface of the earth (extrusive) it will cool with comparative rapidity, and the chemical substances will not have time to gather together

and crystallise into minerals, or at least this process will not be complete, with the result that more or less uncrystallised material, *glass*, will be present. If the flow is thin and quickly cooled the whole mass may be glass, and less glass and more crystals will result the thicker the flow and the slower the rate of cooling. Rocks of this type are *volcanic*. On the other hand, if the molten mass cools very slowly deep down in the earth there is ample time for the whole of the matter to crystallise, resulting in an even-grained rock composed entirely of minerals without the least trace of glass. Such rocks are *plutonic*, and they are said to have a *granitic* structure, not

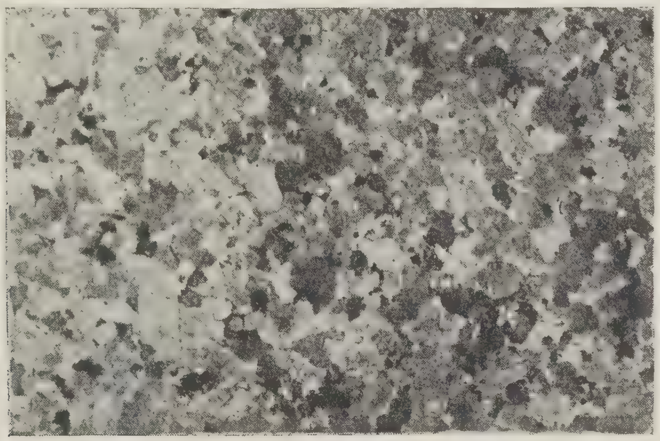

FIG. 6. GRANITE, ILLUSTRATING THE "GRANITIC" OR EVEN-GRAINED STRUCTURE OF DEEP-SEATED IGNEOUS ROCKS

The light mineral is orthoclase, and the very dark mineral is black mica. The intermediate or greyish mineral is quartz, which appears dark in a photograph by reason of its transparency.

because they are necessarily granite, but because they have the even-grained structure seen in that familiar rock. Between the conditions which give rise to volcanic and plutonic rocks there are evidently intermediate ones in which the molten matter fills cracks in the earth or otherwise occupies positions intermediate between the two extremes. Such rocks are likely to present *porphyritic* structure in which some of the minerals are very large and the others form a fine-grained groundmass.

Masses of molten rock (magmas) vary greatly in their chemical composition: those in which there is more than about 50 per cent. silica are commonly called *acid*, and those in which the silica is less than 50 per cent. *basic*. On crystallising, an acid magma is likely to form a rock containing quartz and

orthoclase feldspar and presenting a light colour; on the other hand, a basic magma will form a dark-coloured rock with plagioclase feldspar and much hornblende or pyroxene.

Closely related to the igneous rocks, but not formed directly by the solidification of magmas, are the accumulations of fine-grained debris from volcanoes, *tuffs*, and the coarser accumulations in which angular fragments are visible, *volcanic breccias*.

The chemical composition of igneous magmas is so variable, and the manner of cooling so diversified, that the resulting igneous rocks are not to be regarded like minerals, *i.e.* as definite compounds of fixed composition, but rather as a series of consolidated magmas showing all transitions in chemical and mineralogical composition and in structure from one end of the chain to the other. The following table, which indicates the commonest igneous rocks, is not to be regarded as a rigid classification, but as an orderly arrangement of a few typical rocks between which many transitional stages occur.

CLASSIFICATION OF TYPICAL IGNEOUS ROCKS

(Modified from Kemp)

<table>
<tr><td colspan="4">Acid
Excess of Light-coloured Minerals</td><td colspan="3">Basic
Excess of Dark-coloured Minerals</td></tr>
<tr><td>Glassy structure; volcanic origin</td><td colspan="3">Obsidian</td><td colspan="2">Andesite obsidian</td><td>Basalt Obsidian</td></tr>
<tr><td></td><td colspan="3">Chief feldspar orthoclase</td><td colspan="2">Chief feldspar plagioclase</td><td>No feldspar</td></tr>
<tr><td></td><td>With quartz</td><td>Without quartz</td><td>With nepheline</td><td>With biotite or hornblende or both</td><td>With pyroxene</td><td></td></tr>
<tr><td>Vesicular, glassy or fine-grained structure; volcanic origin</td><td>Rhyolite</td><td>Trachyte</td><td></td><td>Andesite</td><td>Basalt</td><td>Augitite</td></tr>
<tr><td>Porphyritic structure; intrusive or dike origin</td><td>Quartz porphyry
Granite porphyry</td><td>Trachyte porphyry
Syenite porphyry</td><td></td><td>Andesite porphyry
Diorite porphyry</td><td>Basalt porphyry
Gabbro porphyry</td><td>Pyroxenite porphyry
Peridotite porphyry</td></tr>
<tr><td>Granitic structure; plutonic origin</td><td>Granite</td><td>Syenite</td><td>Nepheline syenite</td><td>Diorite</td><td>Gabbro
Diabase
Norite</td><td>Pyroxenite
Peridotite</td></tr>
<tr><td>Fragmental</td><td>Rhyolite tuffs and breccias</td><td>Trachyte tuffs and breccias</td><td></td><td>Andesite tuffs and breccias</td><td colspan="2">Basalt tuffs and breccias</td></tr>
</table>

A careful analysis of this table will save the student much mere memory work in acquiring a knowledge of igneous rocks. The horizontal columns indicate rocks of similar structure, while the vertical columns indicate rocks of similar chemical and mineralogical composition.

After having considered the obsidians we will take up the rocks according to their arrangement in vertical columns. We thus have series or groups of rocks similar in chemical and mineralogical composition but differing in structure and mode of origin. These groups may conveniently be designated by names compounded of the first and last representative, thus "rhyolite-granite series."

Obsidian. The characteristic feature of obsidian is its glassy structure. Typical examples look like a piece of dark green or brownish bottle glass. According to chemical composition obsidians range from the acid type, obsidian proper, through andesite obsidian to the basic, basalt obsidian. Incipient crystals may be present and the rock may be more or less filled with bubbles: pumice is an extremely bubbly or vesicular volcanic glass.

Rhyolite-granite series.

Rhyolite. This is a volcanic rock of light colour and very fine-grained (felsitic) structure. It is made up of a large amount of orthoclase, usually a little plagioclase, quartz, and a less amount of the dark minerals which may be biotite, hornblende, or pyroxene. Bubbles are sometimes present as in most volcanic rocks.

Quartz Porphyry. This rock, sometimes called rhyolite porphyry, is of the same chemical and mineralogical composition as rhyolite: it differs, however, in that some of the quartz and orthoclase crystals are much larger than the finer grained minerals that make up the rock mass; in other words, the structure is porphyritic. The rock occurs in dikes, in intrusive sills, and even in the thicker flows of lava. Unlike the volcanic rocks, quartz porphyry is free from bubbles.

Granite Porphyry. This rock resembles quartz porphyry in the development of large crystals of quartz and orthoclase; it differs in that the groundmass is not fine-grained as in quartz porphyry, but made up of crystals of fair size. The

rock is simply a granite in which certain crystals reach porphyritic dimensions.

GRANITE. This is the deep-seated or plutonic representative of the rhyolites and quartz porphyries: it is distinguished by the fairly coarse and even grain of all the constituent minerals. Many varieties of granite are known according to the development of the dark-coloured minerals. The most typical granite is made up of quartz, orthoclase, and muscovite; by a replacement of the muscovite by other minerals we have *biotite granite, hornblende granite,* etc.

GRANODIORITE. Rocks intermediate in composition between granite and diorite are of common occurrence; they are characterised by the presence of both kinds of feldspar. Typical granodiorite is a rock of granitic structure and appearance composed of quartz, orthoclase, plagioclase, and one or more of the dark-coloured minerals, hornblende and biotite. Many of the so-called granites of Canada are really granodiorites. This rock does not fall into the classification given in the table: it is but one example of the many intermediate types which exist.

RHYOLITE TUFFS AND BRECCIAS. Fragmental rocks formed of volcanic debris having the chemical composition of the rhyolite-granite series. The types of finer grain are *tuffs,* and those showing angular fragments are *breccias.*

Trachyte-syenite series.

TRACHYTE. This is the volcanic representative of a group of rocks characterised by preponderating orthoclase feldspar and no quartz: it may be called a quartzless rhyolite. The structure is felsitic and bubbles may be present as in rhyolite.

TRACHYTE PORPHYRY. A trachyte groundmass with porphyritic crystals of orthoclase. The intrusive or dike representative of the series.

SYENITE PORPHYRY. A groundmass of fair-sized and even-grained orthoclase and mica or hornblende with porphyritic crystals of orthoclase.

SYENITE. The plutonic representative of the series. The rock is composed of fair-sized, even-grained orthoclase and mica or hornblende or both: it is simply a quartzless granite.

Syenite is popularly confused with granite, but it may easily be distinguished by the absence of quartz.

Trachyte Tuffs and Breccias. The fragmental representatives of the trachyte-syenite series.

Nepheline Syenite. Syenite in which the orthoclase is in part replaced by nepheline. Nepheline-bearing rocks corresponding to the other members of the series are known, but they are of less importance to the beginner.

Andesite-diorite series.

Andesite. This rock is the volcanic representative of a series of intermediate chemical composition which gives rise to preponderating feldspar of the plagioclase type and to hornblende as the most typical of the dark-coloured minerals. As in composition, the rocks of the group are intermediate in colour between the light rocks like granite and syenite and the dark basic rocks of the last two columns of the table. The structure of andesite is felsitic, as in rhyolite and trachyte, but the colour is somewhat darker. The mineral components are typically plagioclase and hornblende or biotite: when quartz is present the rock is called *dacite*, and when pyroxene is present it is *augite andesite*.

Andesite Porphyry. The dike representative of the series. It resembles andesite in chemical and mineralogical composition, but has porphyritic crystals of plagioclase.

Diorite Porphyry. Like andesite porphyry, but the groundmass is no longer felsitic but composed of crystals of fair size.

Diorite. The plutonic representative of the series: it is composed of fairly large and even-sized crystals of plagioclase and hornblende. The rock is hard and tough, usually greenish in colour, and darker than the corresponding granites and granodiorites. In *mica diorite* the hornblende is replaced wholly or in part by biotite.

Andesite Tuffs and Breccias. Fragmental rocks composed of volcanic debris having the general composition of andesite.

Basalt-gabbro series.

Basalt. This is a very common rock of volcanic origin and more basic composition than those already mentioned.

The structure is felsitic but some glass may be present. In mineral composition it differs from andesite by the replacement of hornblende by pyroxene. Olivine is frequently present as well as grains of magnetite. The structure is often cellular and rough; sometimes the cavities are large and are known as amygdaloids on account of their almond-like shape. Basalt is a heavy, dark-coloured, variable, and rough type of stone.

Basalt Porphyry. Basalt with porphyritic crystals of augite and frequently also of olivine.

Gabbro Porphyry. A rock of the chemical and mineral composition of basalt, but with porphyritic crystals of pyroxene or olivine imbedded in a groundmass of plagioclase and pyroxene of fair size.

Gabbro. This is a dark-coloured, heavy, and massive rock composed of even-grained and fairly large crystals of plagioclase and pyroxene. In structure it is comparable with the granites, syenites, and diorites. Gabbro in which the ordinary pyroxene is replaced by the rhombic variety, hypersthene, is known as *norite*.

Diabase. In mineral composition this rock is the same as gabbro, but in texture it is intermediate between gabbro and basalt. The feldspar crystals are much elongated and seem to have crystallised first, as the pyroxene fills in the spaces between the lath-like plagioclase crystals. By the naked eye diabase can usually be distinguished from gabbro by the reflections from the elongated feldspar crystals on freshly broken surfaces.

Augitite-peridotite series.

Augitite. This is a rather rare rock resembling basalt to the naked eye. On close examination, however, it is seen to contain no feldspar and to consist essentially of augite embedded in a glassy groundmass.

Pyroxenite. A heavy, ultra-basic, dark-coloured rock consisting essentially of fair-sized, even-grained crystals of pyroxene.

Peridotite. Resembles pyroxenite but contains also olivine.

Pyroxenite and Peridotite Porphyries. Pyroxenites and peridotites in which porphyritic crystals are developed.

Basalt Tuffs and Breccias. The fragmental volcanic rocks of basic composition are generally referred to by this name as the exact texture and mineral composition are hard to determine.

SEDIMENTARY ROCKS

In another chapter will be found an account of the manner in which the debris derived from the decay of pre-existing rocks is spread out by water, and in some cases by wind or other agency, to form the sedimentary or stratified rocks. The present chapter deals only with the naming and classification of rocks of this kind.

The stratified rocks may be classified as follows:

1. Mechanical sediments:
   (*a*) Undecomposed fragments of earlier rocks.
   (*b*) Chemically altered residues of earlier rocks.
2. Rocks formed by organic agencies.
3. Chemical precipitates from solution.

1*a*. When a rock is broken up by the action of natural forces, the fragments may be carried into the sea and laid down in beds. At first these beds are soft and incoherent, but eventually they become hardened; in either condition they are *rocks* in the geological use of that term. The hardening may result from mere pressure, but generally it is caused by the setting of some cementing matter around the fragments. Three types are recognised according to the size and shape of the fragments—breccia, conglomerate, and sandstone.

Breccia. This rock is made up of *angular* fragments of earlier rocks cemented by some foreign matter—clay, lime, silica, or other substance. Breccias are formed near to the point of origin of the fragments which have not been rounded by transportation. These rocks are sometimes named in accord with the nature of the fragments, thus *limestone breccia*, *granite breccia*, etc. They are also named in accord with their method of origin, as *talus breccia* formed at the foot of a cliff, *friction breccia* formed by the rubbing together of rocks in earth movements. We have already seen that angular volcanic fragments cemented into a rock also form breccias.

CONGLOMERATE. Beds of gravel cemented into solid rock in the same manner as in the case of breccia become conglomerates or "pudding stones." These differ from breccias only in the rounding of the component fragments. This condition indicates that the fragments have been subjected to the action of currents, or waves, or ice, and that they did not of necessity originate in the locality in which they are found.

Conglomerates are usually named from the character of the component fragments of rock; for instance, *jasper conglomerate* is a very handsome decorative rock composed of

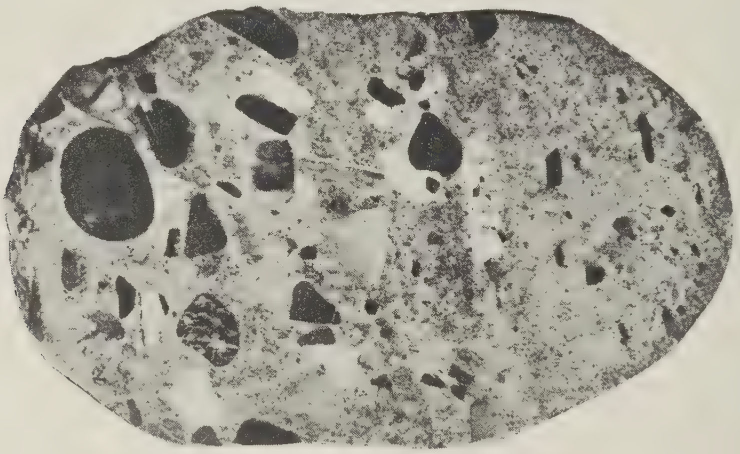

FIG. 7. JASPER CONGLOMERATE

The rounded dark fragments are bright red jasper; the groundmass is chiefly quartz.

rounded fragments of red jasper cemented by silica. Frequently the component pebbles are of a nature so varied that it is impossible to name the rock on this basis. Conglomerates of glacial origin, with ice-worn pebbles embedded in a clay matrix, are known as *tillites*.

SANDSTONE. Sand is made up of the finer fragments derived from earlier rocks. In most cases the breaking up of the original rock has been so complete that each grain of sand is a fragment of a distinct mineral. Naturally the more resistant minerals have better survived the processes of decay; in consequence, the hard mineral, quartz, is of most frequent occurrence in sand beds; but feldspar, garnet, magnetite, mica, and other minerals of the igneous rocks are by no means absent. In the coarser sands, fragments of rock

matter not reduced to individual minerals are often to be observed.

Beds of sand become hardened into sandstones, chiefly by the setting of cementing matter between the grains. The commonest cements are clay, silica, lime, and the oxides of iron. The character of the cement is made use of to give a name to the sandstone; thus we have clayey or argillaceous sandstones, siliceous sandstones, calcareous sandstones, and ferruginous sandstones. It is obvious that the amount of cement may increase until it exceeds that of the constituent grains; for instance, an argillaceous sandstone by an increase of clay becomes an arenaceous or sandy shale, and a calcareous sandstone by an increase of lime passes gradually into an arenaceous limestone.

Sand is used largely in building operations, in glass-making, and in making hearths for furnaces: for the first purpose the greater the proportion of quartz grains the better; for the last two purposes a very high proportion of quartz is essential. Sandstones are used very extensively for building: varieties which may be chiselled with facility are called *freestone*. Sandstones in which the constituent grains are fine and sharp and with just the right degree of cohesion are used for the manufacture of grindstones and scythe-stones.

1*b*. CLAY AND SHALE. The decay of orthoclase feldspar in the igneous rocks gives rise to a new mineral, kaolinite, a soft, plastic, insoluble substance, that is washed down by the rivers and deposited in the sea together with a varying amount of fine sand to build up beds of clay. Pure kaolinite is scarcely known as a stratified rock: clay is composed of kaolinite or related minerals with varying amounts of other substances, chiefly fine sand and carbonate of lime. Hardened clay is known as *shale*.

Clay is one of the most useful substances known to man; in consequence it has received much study and an extensive classification has arisen. Different varieties of clay are suited to various industrial purposes—from the making of common brick and tile to the manufacture of the finest grades of porcelain. The fire-resisting properties of certain clays render them extremely valuable for lining furnaces.

2. LIMESTONE. Carbonate of lime, derived originally from

the decay of igneous rocks, is carried in solution by the rivers and added to the water of the ocean. The inhabitants of the sea make use of this lime to construct shells or other hard parts. On the death of the organism these shells accumulate on the floor of the sea and build up beds of limestone. In many cases the character of the shells may easily be determined, and limestones are sometimes named from the prevailing organism present; thus *encrinal limestone*, largely made up of the remains of encrinites, *coralline limestone*, etc. In other cases, the shells have been so ground up by wave action or currents that they are no longer recognisable as such. Further, a process of solution and re-precipitation in the slimes on the sea floor, and a development of fine crystalline structure, entirely masks the organic origin of the stone.

By an admixture of clay pure limestone becomes *argillaceous limestone*, and with a greater amount of clay it becomes *calcareous shale*. Similarly by an increasing admixture of sand, limestones pass into *arenaceous limestones* and *calcareous sandstones*.

In a chemical way also, limestones are subject to much variation, chiefly by the replacement of part of the lime by magnesia. When the magnesia is 5 per cent. or somewhat more, the rock is called *magnesian limestone*; a still greater amount of magnesia constitutes it a *dolomitic limestone*; and when the magnesia approaches 21·72 per cent. (the percentage in the mineral dolomite) the rock is called *dolomite*. A similar series of varieties is caused by the replacement of carbonate of lime by carbonate of iron.

Infusorial Earth. Organisms which secrete a siliceous skeleton may also build up layers of rock or furnish the material for flints, cherty nodules, or disseminated silica in other stratified rocks. The only important rock of this kind is infusorial earth which is made up of the remains of minute siliceous organisms. This material is of use as an abrading and polishing substance: it is obtained in large quantity near Windsor, Nova Scotia.

Coal. Coal being composed of the remains of plants belongs properly to the category of organic rocks.

3. Gypsum. This mineral is soluble and is a constant constituent of the waters of the ocean; if, under prevailing

desert conditions, a portion of the sea is cut off from the open ocean, evaporation of the water results in the deposition of beds of gypsum.

ROCK SALT. Beds of rock salt are formed in the same manner as those of gypsum.

IRON ORES. Certain types of iron ore, particularly bog iron ore, have been formed in beds by the precipitation of iron from solution in water.

METAMORPHIC ROCKS

Both sedimentary and igneous rocks may be so altered by the effect of heat and terrestrial strains that they lose much of their original appearance and acquire new properties, chemical, mineralogical, or structural; in some cases they differ so greatly from the rocks that gave rise to them that their origin may remain conjectural only. Such rocks are said to have been metamorphosed and they are referred to as the metamorphic rocks.

The subject of metamorphism is a large one and is briefly treated in another chapter. We shall consider here only the rocks themselves without regard to the details of their origin.

GNEISS. In the narrower sense this name is given to rock, originally granite, which has acquired a banded or laminated structure as the result of metamorphism. Instead of the mineral components being uniformly distributed as in granite, they are rolled out into more or less distinct laminæ, with the result that the rock shows alternating bands of the light- and the dark-coloured components. All gradations are known between a distinct granite and a highly laminated gneiss. For the intermediate types the terms *granitoid gneiss* and *gneissoid granite* are used. Gneiss may also be formed by the intense metamorphism of beds of clay. This kind of gneiss is usually more distinctly laminated and is liable to contain accessory minerals such as garnet and sillimanite. The term *paragneiss* is used to distinguish the rock of clay origin from that of granite origin which is called *orthogneiss*.

Some authors use the word "gneiss" to designate any of the plutonic igneous rocks which have acquired a laminated structure through metamorphism; thus we have syenitic, dioritic, pyroxenitic, and other gneisses.

Schists. The schists are usually of finer lamination than the gneisses, but if that term be used in the broader sense it is difficult to establish a sharp line of division between the two rocks. Schists may be defined as rocks of crystalline structure, usually showing a pronounced lamination. They may be formed by the metamorphism of either igneous or sedimentary rocks. Schists are usually named from the most conspicuous mineral present.

Mica schists are finely laminated rocks composed essentially

Photo. by J. Keele

FIG. 8. TYPICAL GNEISS, KILLALOE, HAGERTY TOWNSHIP, ONT.

of some variety of mica and quartz; thus we have biotite, muscovite, sericite, and other mica schists. Mica schist passes insensibly into gneiss by the gradual increase of feldspar.

Hornblende and chlorite schists result from the metamorphism of the basic igneous rocks in which pyroxene is a prominent component. The alteration consists of the passage of the pyroxene into hornblende or chlorite and the acquisition of a banded structure. Some hornblende schists are fairly massive and the laminated structure can be seen only on

careful examination. Talc and epidote schists are other examples of schists in which secondary minerals are present.

SLATE. Slate is a metamorphic rock resulting from the strong alteration of shale. The familiar cleavage of slate is not a parting parallel to the original bedding of the clay, but is the result of terrestrial strains which have acted on the rock and induced a parting at right angles to the direction of pressure. Highly metamorphosed slate shows mica as a constituent and is called *mica slate*; less altered types, without a development of mica, are called *clay slates*.

QUARTZITE. This rock is metamorphosed sandstone: it is usually very hard and compact, the grains of quartz being closely pressed together and frequently cemented by secondary silica into a remarkably hard rock. Naturally there are many varieties of quartzite depending on the purity of the original sandstone. Conglomerates and breccias give rise to corresponding metamorphic rocks.

GREYWACKE. This is a very useful if somewhat indefinite term; it is applied to metamorphic rocks intermediate between slates and quartzites. Greywacke results from the metamorphism of shaly sandstones: it is tough and usually breaks with an irregular fracture on which ill-defined fragments of the original rock, rather than distinct minerals, are to be observed.

CRYSTALLINE LIMESTONE. Ordinary limestone under metamorphic influences acquires a crystalline structure and is then termed crystalline limestone. The grain may vary from fine to very coarse. Fine-grained types, when of sufficient beauty for decorative purposes, are called *marble,* but this term is of rather indefinite significance as it is used for limestones other than crystalline if their appearance justifies their use as decorative material. As in the case of unaltered limestones, magnesian and dolomitic crystalline varieties are common.

SERPENTINE. By the alteration *en masse* of basic igneous rocks rich in the dark-coloured minerals, serpentine is formed on a scale which justifies the use of the name for the rock as well as for the mineral.

CHAPTER III

DYNAMIC GEOLOGY

The earth is not an inert sphere endowed only with planetary motions, but is constantly being moulded in all its parts by the action of physical and chemical forces. The pull of gravity, the effects of heat, light, and electricity, the power of chemical affinity and other molecular attractions, and the results of radioactivity all have their place in shaping and modifying the earth as a whole and its various parts. Even living beings, each individual insignificant, by cumulative effects may cause important changes in the earth, so that biology as well as physics and chemistry must be drawn upon to understand the constant adjustments to which the earth is subject.

The sources of the energy at work in the world are to be sought partly in the earth's internal stores of heat and partly in energy radiated from without, principally from the sun. It is evident that the work of the earth's internal heat will be mainly subterranean and out of reach as far as direct observation is concerned; while the heat, light, and other energies coming from the sun play all about us and cause most of the familiar phenomena by which the surface is shaped. With the exception of tidal effects due to the pull of the moon, and the relatively faint radiations reaching the earth from the stars, the changes taking place are due either to the earth's internal heat, giving rise to *hypogene* action, or to radiations from the sun, the *epigene* forces. We may then divide Dynamic Geology into two parts, Hypogene and Epigene: the first dealing mainly with deep-seated forces, and the second mainly with superficial ones.

HYPOGENE FORCES

It may be said generally that the earth is a heat engine. Its interior is hot and heat is constantly radiating into space, and as a result work is being done in various ways. It will

be desirable to consider first the heat relations of the earth and then the ways in which the work is done. In this connection slow changes of level in the earth's crust are of great importance. These may result in sudden adjustments of the strata, causing dislocations, fissuring, and earthquakes, and may permit molten rock to move below the surface, or break forth on the surface, forming volcanoes. Slow transformations of the minerals in rocks beneath the surface may take place by means of pressure, motion, heat, and circulating liquids connected with molten rocks, causing metamorphism. The hypogene activities may be discussed then under the heads of:

Condition of the Earth's Interior.
Secular Changes of Level.
Earthquakes.
Volcanoes.
Metamorphism.

CONDITION OF THE EARTH'S INTERIOR

The surface of the earth consists of cold and solid rock, where it is visible on the land, and the same is no doubt true beneath the ocean, which at great depths, even within the tropics, has a temperature not far from the freezing point. In all parts of the world where mines or deep wells have been sunk we find, however, that the temperature rises below the depth of 50 or 60 feet at which seasonal changes cease. The rate of increase varies a good deal, sometimes being as rapid as 1° F. in 28 feet (Comstock Lode), and sometimes as slow as 1° F. in 120 or 130 feet, as at the Calumet and Hecla mine in Michigan. It is generally stated that the average rate of increase in temperature is about 1° F. in 60 feet, or 1° C. in 30 metres or 100 feet. The most recent and careful work, carried out in the sinking of wells in Pennsylvania and West Virginia, where a depth of over 7000 feet was reached, gives an increase of 1° F. in from 46 to 51 feet; a much more rapid rate than has usually been found. The deepest well, that of Clarksburg in West Virginia, reached 7386 feet, with an average rise of temperature of 1° F. in 51 feet.

If one assumes the rate to be 1° C. in 100 feet, as a round

number, and also that the rate continues the same for great depths, it is evident that the temperature two miles below the surface would be greater than 100° C., *i.e.* above the boiling point; that at 20 miles it would be over 1000° C., far above red heat; and that at a sufficient depth a temperature would be encountered capable of melting any known substance under ordinary surface conditions.

Levels at which equal temperatures occur may be called *isogeotherms*.

It was believed in earlier times that the interior of the earth, beneath the solid crust, was molten, or even, as some thought, gaseous; but there are conclusive proofs that the earth as a whole is solid, in fact even as rigid as steel. For instance, earthquake waves are transmitted through the earth at a speed possible only in a highly rigid solid; and the tides of the ocean would be imperceptible if the earth were liquid within a moderately thick crust, since the internal tides would leave very little margin for oceanic tides.

We must assume then that no large part of the earth's interior is liquid and either that the downward increase in temperature gradually diminishes and finally ceases, or that the pressure of the vast load of overlying rock compresses the materials beneath, preventing the expansion necessary to change a solid to a liquid. Perhaps both assumptions are true. It should be remembered that our explorations into the earth's crust have not gone beyond 7386 feet, less than a mile and a half, while the earth's radius is nearly 4000 miles; so that we really know very little directly as to conditions at great depths.

Unless one accepts the nebular hypothesis, which assumes that the earth began intensely hot and has not yet lost all its heat, the cause of the high temperature of the earth's interior becomes a matter of interest, and several suggestions have been made to account for it. The final result of most kinds of work is to cause heat, so that mechanical work alone on a sufficient scale could provide the necessary temperature. This work might be due to compression, to tidal kneading caused by the pull of the moon and sun, etc. Even chemical action, such as the burning of fuel, has been suggested, though this cannot be of importance. The most surprising cause of

the heat below the surface of the earth has been made known rather recently, in the discovery that the rocks making up the earth's crust often contain radioactive substances which are constantly giving off heat. Some physicists even state that the heat provided in this way more than balances the losses into space, so that the earth is really warming up and not cooling down.

SECULAR CHANGES OF LEVEL

Except in earthquake regions one is apt to think of the earth's crust as immovable, to regard it as *terra firma*, and yet, given a sufficient change of conditions and length of time, very important changes of level may take place, amounting even to many thousands of feet. So far as known, these changes go on usually with extreme slowness, hence the term "secular" changes of level. It is probable that most parts of the earth's surface have changed their level within recent geological time, and that some parts are now rising or sinking.

It is evident that to recognise these slow changes one should have a standard of comparison, and the one adopted is the mean level of the sea, reversing the usual impression of the instability of the sea and the firmness of the land. As the sea covers nearly three-fourths of the earth, and the different oceans have broad connections, it will theoretically take the shape of a spheroid of rotation under the combined influences of the pull of gravity towards the earth's centre and of the centrifugal force due to its rotation every twenty-four hours. Unless there are changes in the amount of water on the earth this spheroid should make a very constant datum plane.

In reality, however, there are disturbing factors. Coastal mountain ranges, like the Cordillera along the Pacific, undoubtedly pull the water towards them; and in great ice ages vast volumes of water, perhaps millions of cubic miles, are removed temporarily from the sea, lowering its surface over the whole earth. The piling up of such a weight of ice in the northern hemisphere must have shifted the earth's centre of gravity to the northwards, which would mean a raising of the level in northern seas and a sinking in the

southern hemisphere. It is probable that such changes in the level of the sea at a given place may have reached one hundred or even two hundred feet. It has been suggested also that the total amount of liquid water in the world may be steadily diminished in the process of weathering when hydrous compounds take the place of anhydrous ones. On the other hand, the steam given off by volcanoes represents the transfer of water (magmatic or juvenile) from the earth's interior to its surface. Perhaps the two processes roughly balance one another. However, in a general way we may consider the sea as forming a fairly constant base level with which to compare the land. Fortunately the sea leaves a distinct mark in the form of beaches and wave-cut terraces with cliffs behind them where it has worked for any length of time, so that its former levels can often be recognised at a glance.

EVIDENCES OF SLOW CHANGES OF LEVEL IN RECENT TIMES

Proofs of sudden changes of level connected with earthquakes are not uncommon, as will be mentioned later, but historic evidence of gradual changes is harder to get, probably because of the slowness of the motion. One instance, that of the supposed temple of Jupiter Serapis near Naples, is usually cited. This temple is reported to have been repaired in Roman times, when it must have been on dry land. At present the ruins of the temple are just awash with the sea. Three marble pillars which still remain standing show holes bored in the marble by marine shellfish up to a level of about twenty feet. It is evident that the temple must have been sunk beneath the Mediterranean to that depth and then raised to its present level; and these changes

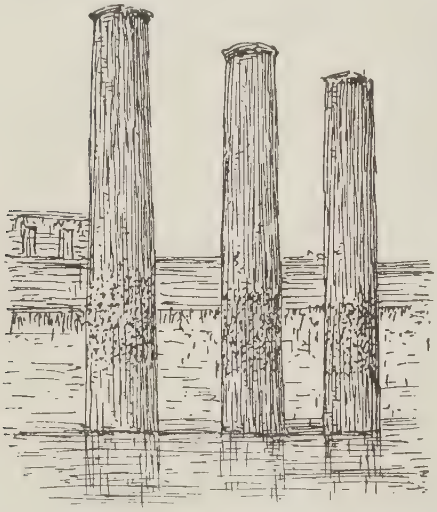

FIG. 9. THE THREE STANDING COLUMNS OF THE TEMPLE OF JUPITER SERAPIS, NEAR NAPLES

took place in less than 1700 years. However, Naples is in a volcanic region where rapid adjustments might be expected.

Proofs of such gradual changes within a few hundred years have been found in Scandinavia, where the northern shores of the Baltic in Sweden and the North Cape in Norway are believed to have risen, while at the south end of Sweden, as at Malmoe, paved streets beneath the level of the sea show depression. Scandinavia seems to have been swinging on a pivot, the northern end rising and the southern sinking, and it is supposed that these movements are still progressing.

Some geologists believe that similar movements are taking

FIG. 10. RAISED BEACHES, SPITZBERGEN

place in America, but others oppose this, and it is probable that the land here is nearly, if not altogether, at rest. There are, however, unmistakable proofs that eastern Canada and the north-eastern states have risen hundreds of feet in geologically recent times, since the ice of the Glacial period left the region; for marine beaches, often still containing sea-shells, are found in many places, gradually ascending northwards, from 330 feet at Brockville to 600 feet on Mount Royal and 690 feet north-west of Ottawa. Similar beaches are found in Labrador and around Hudson bay, as well as on the Pacific coast, indicating that the whole region was depressed by the load of ice and rose again when the ice was removed.

On the other hand, there is evidence of a sinking of the land in some parts of eastern Canada, as near Wolfville in Nova Scotia, where stumps of trees are to be seen at low tide, fifty feet below the level at which trees grow at present, and at Chignecto on the isthmus connecting Nova Scotia and New Brunswick, where excavations for a proposed ship railway disclosed a peat bed sixty feet below high tide.

Moderate changes of sea level, like those just mentioned, may be accounted for naturally by a reference to the general lowering of the sea, due to the amount of water required to form the great ice sheets of the Glacial period.

This cause is, however, quite inadequate to account for the old channel of the St. Lawrence, which can be followed to a depth of 2000 feet or more at the edge of the continental shelf, where the deep sea begins. It is evident that eastern Canada stood at least 2000 feet higher than it does at present when the river cut this ancient channel.

This great elevation came before the Ice age and was followed by a depression when the raised beaches, mentioned earlier, were formed. Both stages belong to geologically recent times.

CHANGES OF LEVEL IN MOUNTAIN BUILDING

Much greater changes of level are recorded in most mountain ranges, as shown by the sea-shells enclosed as fossils in the limestones and shales of the Rockies more than 10,000 feet above the sea. In the Andes such marine fossils are found at 15,000 feet, and in the Himalayas at 20,000 feet or more. The mountain tops have, then, been formed of sediments of the sea bottom thrust up miles above their original position.

Almost all high mountains, as well as tablelands, give evidence of their origin as marine sediments. The cause of this will be discussed later.

DEPRESSION OF THE SEA BOTTOM

Evidence of profound depressions of the sea bottom are naturally harder to find, since the proofs must be out of reach beneath the ocean. Biologists and palæontologists often account for the distribution of plants and animals by assuming

vanished continents, or at least land "bridges" connecting continents or islands now separated by deep seas. One of the most striking examples of this line of argument is founded on the distribution of the wingless birds of the southern hemisphere. The ostrich in Africa, the rhea in South America, the apteryx of New Zealand, and the emu of Australia, as well as the extinct æpyornis of Madagascar are all flightless birds on southward projecting lands separated by seas 12,000 feet or more in depth. The supposition is that these lands were once connected with one another, perhaps by way of the Antarctic continent, and that the running birds then made their way to their present homes. This evidence for great depression of the land does not seem as certain, however, as that for great elevation in mountains, and there are authorities who deny that continents and deep sea bottoms have ever changed places.

ISOSTASY

There are proofs that at present the earth's crust nearly approaches a condition of *isostasy*, *i.e.* that highlands are high because they are made of lighter materials than lowlands, and that the surface stands about at the level corresponding to the specific gravity of the rocks beneath. If the theory that the earth's crust is in a state of "isostatic equilibrium" is correct, it makes an interchange of continents and ocean depths very hard to account for, and suggests caution in assuming great changes in the relations of land and sea.

EPEIROGENESIS AND OROGENESIS

Changes in level of the earth's crust may be divided broadly into two kinds: *epeirogenic* (continent building), where continental surfaces are widely elevated or depressed without much buckling or fracture; and *orogenic* (mountain building), where bands of the lithosphere are thrust into folds or tilted up as blocks that ride upon one another, forming ranges of mountains.

The changes of level referred to in eastern Canada are of the epeirogenic kind, while the Rockies and other western mountain ranges afford excellent examples of orogenesis.

Orogenesis gives rise to the most striking relief features of the land, and the building of mountain ranges results from the concentration of tremendous thrusts along a line of weakness in the earth's crust.

A region that has undergone orogenesis may have its mountains carved down during the lapse of ages to low hills, so that its mountainous character is lost, and subsequently may be elevated or depressed in epeirogenic ways. Northeastern Canada illustrates this excellently.

The terms used above apply to movements of the land; but there can be no doubt that the crust of the earth beneath the sea undergoes similar changes of level. Bordering mountainous coasts there are often narrow, deep depressions, "troughs" or "deeps," like reversed mountain ranges; and there is good evidence of risings and sinkings of the sea bottom on a broader scale.

DIASTROPHISM

Changes of level affecting the boundaries of land and sea are known to have taken place at many times in the past; but usually they have been of a local kind, the lowlands settling to allow the advance of a shallow sea, or the sea bottom becoming a coastal plain through a gentle rise of the land. Recent developments of Stratigraphical Geology suggest, however, that from time to time there have been widespread changes of level, perhaps affecting all the continents at about the same time, serving to mark off the major divisions of geological time. Much importance is now attached to these epochs of rising and broadening continents, and to the reverse stages when shallow seas encroach widely upon the continents. These readjustments of the earth's crust are included under the term *diastrophism*, and there is some reason to believe that such world-wide changes occur with a gigantic rhythm, extending over millions of years, and that the climates of the earth are modified to correspond with the broadening or the narrowing of the land surfaces.

CAUSES OF CHANGES OF LEVEL

Assuming that the principle of isostasy is correct, changes of level may be accounted for by changes of load. If a mile

of ice is piled on north-eastern America, the region will sink under the burden and the sea will encroach correspondingly on the margin free from ice. If the ice melts, the load is removed and the land rises. The raised beaches of Ontario and Quebec may be accounted for in this way.

Where erosion is going on, the burden of the land will be lightened and the land will rise; while the shallow sea bottom on which rivers are depositing sediments will tend to sink. In this way thousands of feet of mud and sand may be laid down at about the level of the sea, as happened at the Joggins, in Nova Scotia, where 13,000 feet of sediments accompany the coal measures, probably all formed at much the same level.

In the building of mountain chains a much more important factor seems to come in, that of lateral thrust due to a shrinkage of the earth as a whole.

If we imagine the earth's crust to be solidly adjusted for a particular radius and the interior of the earth to be shrinking, it is evident that the crust must yield to correspond. The yielding will naturally take place along lines or belts of weakness, where the rocks will be thrust into folds or broken into long slices which ride upon one another, thus taking up the slack due to the shrinkage. For instance, it has been estimated that the eastern half of the Rockies at Bow Pass has been narrowed twenty-five miles by the overriding of longitudinal blocks, the outermost having been pushed seven miles out upon the prairies.

This buckling and telescoping of the rocks is found in all great mountain ranges, and is prepared for in a very singular way. For ages before the range is elevated, sediments are heaped on a slowly sinking band of shallow sea bottom until 20,000 or even 50,000 feet have accumulated in what may be called a "geosyncline." The firm floor beneath is depressed into warmer levels and thus weakened, and finally the lateral thrust overcomes its resistance and the mountains are raised relatively suddenly. An illustration will be given later when the history of the Rocky Mountains is taken up.

While this bending and breaking of the beds in belts of weakness thousands of miles long is certain, and is attributed usually to thrust of the sea bottom against a resisting mass of land—a continent—there are difficulties in providing for a

sufficient amount of shrinkage to account for the requisite shortening of the earth's circumference. The earliest suggestion was that the earth had cooled and therefore contracted, producing the lateral pressure; but the amount of slack taken up in the crumplings of the world's mountain chains far exceeds any probable shrinkage due to loss of heat, and, as mentioned earlier, it is doubtful if the earth really has been cooling down.

Other suggestions have been the loss of lava, which comes from miles beneath and is poured out on the surface, and the loss of volatile constituents once contained in the earth's interior, such as the steam and gases coming from volcanoes. Compression of the materials of the earth under gravity and also the rearrangement of the materials into new and denser compounds are possible. If the earth was built up of planetesimals, small cold particles falling in from space, they may have been loosely packed in the beginning and may have been more and more closely crowded as time went on.

It must be admitted that no very satisfactory theory has yet been proposed to account for the tremendous compression of the earth's crust shown in mountain ranges.

MOVEMENTS IN THE ASTHENOSPHERE

Where a great area of land is elevated in epeirogenic changes one must assume either that the supports beneath have expanded, *e.g.* by rise of temperature, or that there has been a movement of matter beneath to support the lithosphere in its new position. The earth's crust is far too weak to stand like an arch with a void beneath. The lithosphere rests upon an asthenosphere, a sub-structure that is not liquid, that for momentary stresses, such as earthquake waves, acts as a very rigid solid, but that is loaded beyond its crushing strength by the column of rock above. This asthenosphere is believed to undergo slow motions, suggesting the flow of a very viscid material, following up and supporting the rising crust above.

Where depression occurs, on the other hand, there must be a slow outflow to permit the sinking of the lithosphere. These extremely sluggish subterranean movements must exert a dragging effect on the lithosphere above, and it has actually

been proved by triangulation in the Californian earthquake region that such movements have taken place, points on one side of a great line of fracture having shifted their relative positions three or four metres since the region was first mapped.

Given sufficient time, effects of great magnitude may be produced by the gradual shiftings of the asthenosphere beneath the solid crust.

EARTHQUAKES

It has been shown that great changes of level take place at many points on the earth's surface, and that the rocks in mountain chains are thrown into long flexures or even broken

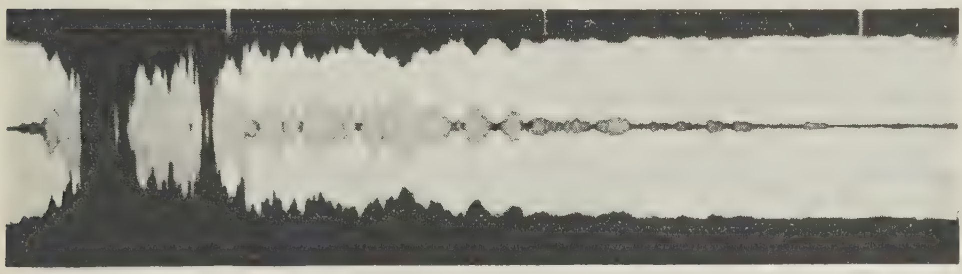

FIG. 11. SEISMOGRAM OF SAN FRANCISCO EARTHQUAKE, APRIL 18, 1906
Recorded at the Observatory, Toronto, Ont.

asunder. Some of these movements appear to take place quietly with no rupture of the beds, but others cause strains which are suddenly relieved, the rocks breaking and rearranging themselves by faulting. Such sudden and violent readjustments cause earthquakes. Naturally earthquakes are most frequent and violent where mountains are being raised, and especially where lofty mountain ranges rise rapidly beside deep seas.

Of late years our knowledge of earthquake motions has been put on a solid footing by the records of seismographs, instruments for recording shocks. A simple form of seismograph consists of a boom of steel wire lightly supported by a silk thread and playing loosely in a socket. At the end of the wire a small mirror reflects a ray of light down upon a band of sensitised paper kept in regular motion by clockwork. The ray of light is photographed as a straight line when the

seismograph is at rest, but when shaken by earthquake waves the line becomes a zigzag or even swings quite off the band of paper if the motion is violent. These instruments are so sensitive that a heavy shock is recorded at stations thousands of miles away. Seismographs at Toronto, Ottawa, and Victoria have recorded earthquakes which took place in Japan, San Francisco, Valparaiso, Jamaica, etc.

Three kinds of wave motions have been proved by the aid of seismographs, one which travels on the surface of the earth and two others transmitted through the earth along paths with a somewhat inward curve. The surface waves are slowest, with a rate of 3·8 kilometres (about 2 miles) per second. The others have rates of 12·8 kilometres (8·48 miles) and 6·84 kilometres (4·53 miles) per second when at a distance of 100° of arc from the starting point of the shock.

Though all great earthquakes are recorded by Canadian seismographs no destructive earthquake has taken place in Canada within historic times, since the Dominion is one of the most ancient and stable parts of the earth. The most serious Canadian earthquake on record occurred in Quebec in 1663, when for months there were small shocks swaying the trees, so that the Indians said "the trees were drunk." The only important effects noted were landslides along the river banks. To study destructive earthquake action at first hand a Canadian must go to other lands, though somewhat severe shocks sometimes occur at Victoria and other points in British Columbia.

The place of origin of an earthquake is called the epicentre, an ill-chosen word, since the shocks do not begin at a point, but along a plane which may even be hundreds of miles in length. Since the breaking of the rocks which causes the shock must take place within the "zone of fracture," the centre from which the motions originate cannot be at any great depth; and frequently the movement is evident at the surface, one side slipping down a few feet, as in the Mino-Owari earthquake in Japan (eighteen to twenty feet), and the Shillong earthquake in India and Assam, when a shifting of twenty-five or more feet caused a waterfall on Chadrang river.

In the San Francisco earthquake (1906) the San Andreas

fault was affected for a length of 435 kilometres, but the displacement was mainly horizontal, amounting to four metres.

The displacement of the strata causing the earthquake may take place with no perceptible warning and may be complete in a few minutes; or it may continue from time to time for months, as in the great Calabrian earthquake. The same fault line may give rise to repeated earthquakes separated by many years of quiescence, as in California. The greatest vertical movement known is forty-seven feet, as shown by the raising of a beach to that height in the Alaskan earthquake of 1899.

Accompaniments of Earthquakes. While the essential feature of an earthquake is the dislocation and adjustment of the solid rocks, there are other important features which should be mentioned. The greatest destruction does not usually happen on the solid rocks themselves but on overlying drift deposits, and especially on "made ground." This was well shown in the San Francisco earthquake, when the lower part of the city on made ground along the harbour suffered most, the effect being compared to the shaking of jelly in a bowl. Great fissures opened in loose ground and much slumping occurred, so that water pipes were crushed and railway lines bent into sharp curves. Often the underground circulation of water is affected, springs ceasing to flow or breaking out in new places, and quicksand being forced up forming miniature craters.

The most important secondary effect along sea coasts is the huge wave which often follows up a withdrawal of the sea, rushing far inland, destroying ships and buildings. During the earthquake which destroyed Port Royal in Jamaica (1692), the frigate *Swan* was driven over the tops of buildings and thrown upon a roof which it broke.

From the human point of view a great earthquake is the most terrifying of natural disasters, since a city may be destroyed in a few minutes, and without warning tens of thousands of people may be killed. There are few years in which some catastrophe of the kind is not reported, such as the earthquake which destroyed Messina with 75,000 of its inhabitants in 1908, or the more recent destruction of the city of Guatemala with great loss of life.

It has been found that certain types of structure resist earthquakes best, those which are made of strong and elastic materials, such as steel, being far more secure than buildings of brick or stone without reinforcement. The business portion of San Francisco has been rebuilt largely with steel-framed structures on this account.

Distribution of Earthquakes. The causes of earthquakes are bound up with the changes of level of parts of the earth's crust, especially where young mountains rise near deep seas, and accordingly we find that earthquakes are prevalent in such regions, as around the shores of the Pacific, in the Himalayan region, the East and West Indies, and the Mediterranean. Not all earthquakes have their origin on the land. There have been settlings of blocks of the sea bottom along the west coast of South America and between Calabria and Sicily which have caused destructive earthquakes. Telegraph cables have frequently been broken in the submarine disturbances.

VOLCANOES

The movements of molten rock at great depths are probably closely bound up with the folding and faulting connected with mountain building, and hence with the causes of earthquakes, which are symptoms of such adjustments. Many of these molten masses cease their movement long before reaching the surface, so that their characteristics can only be studied ages afterwards when erosion has removed thousands of feet of overlying rock. Probably great masses of molten material are set in motion and do important work beneath the axes of rising mountain chains; but these masses become visible to us only millions of years later, as in the Coast Range of British Columbia or the Laurentian region of eastern Canada, and it is proposed to defer a description of them until the structural features of eruptive rocks are taken up, since our knowledge of them is *post mortem*. Their actual operation we cannot observe.

However, in many cases molten material comes to the surface, causing one of the most dramatic displays of terrestrial activity in the form of volcanoes. These are full of interest and can be studied in many places. In early geological

times there was great volcanic activity in several parts of Canada, and in the west it is known that two or more volcanoes have been in eruption since the Glacial period, but none has been reported as active within the memory of man.

The nearest active volcanoes to Canadian territory are those of Alaska, but these have not been very carefully studied, and other examples will be chosen to illustrate the work of volcanoes.

The old idea that a volcano is "a burning mountain" is of course incorrect. There is little actual combustion connected with volcanoes, except as a bye-product of their work when certain gases are given off and burn in the air. The essential feature of a volcano is an opening or vent through which molten rock may reach the surface. At the surface the materials given off usually build a conical hill or mountain with an opening on top, the crater (Greek word for cup).

The lavas of volcanoes in almost all cases are charged with various gases, which seem to have been original constituents of the magma, since in the quartz of granites, which cooled at great depths below the surface, innumerable small inclusions of water or carbon dioxide can often be found under the microscope.

Volcanoes give off, then, liquid rock, called lava, and gases, including in the latter term all substances volatile at a high temperature.

Lava. The word lava does not mean a definite kind of rock, but includes several species of eruptives ranging on the acid side from rhyolite with seventy-five per cent. or more of silica to basic rocks such as basalts which may contain fifty per cent. or less of silica. Trachytes, andesites, etc., lie between these limits. The properties of different lavas vary widely, the more basic ones melting at a temperature of 1100° C. to a very fluid magma, while the acid lavas have a higher melting point and unless very hot are much less fluid. As a result the basic lavas lose their gases more readily than the acid ones and have comparatively quiet, unexplosive eruptions with thin, widely spreading lava sheets. Volcanoes with acid lavas, on the contrary, have explosive eruptions, sometimes with no flow of lava, the whole mass bursting into small fragments or even fine dust. Most volcanoes, however, are of

an intermediate kind with both lava flows and explosions, thus building up a composite cone.

Volcanic Gases. These include water, hydrogen, hydrogen chloride, chlorine, nitrogen, carbon dioxide, carbon monoxide, sulphur dioxide, hydrogen sulphide, and sulphur, with smaller amounts of other gases. The greater part of what is commonly called the smoke of a volcano consists of condensing steam coming either directly from the lava or from the burning of hydrogen. Some authorities believe, however, that most of the steam is really due to the evaporation of rainfall; and ammonium chloride is thought by some to be an important part of the volatile matter. It condenses as a white coating

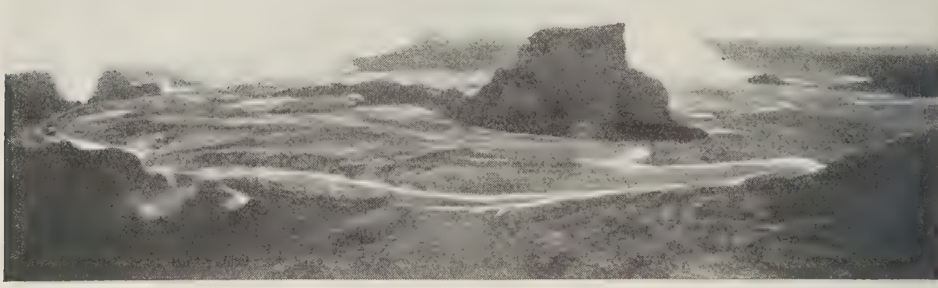

FIG. 12. CRATER OF MOUNT KILAUEA, HAWAII
From Report of U.S. Geological Survey.

on the upper cone of Etna. The sulphur which is volatilised or formed by combining one part of sulphur dioxide with two parts of hydrogen sulphide is deposited in craters approaching extinction.

Volcanoes with very Fluid Lavas. Two Hawaiian volcanoes, Kilauea and Mauna Loa, are famous for their very fluid basaltic lavas, giving rise to non-explosive eruptions. Kilauea (4000 feet) has been observed for many years and its habits are well known, and Mauna Loa, twenty miles away and nearly 10,000 feet higher, has similar eruptions. Owing to the fluidity of the lava of which these mountains have been built their slopes are very gentle, about seven degrees, and the top has almost the appearance of a plain, with a large steep-walled and flat-bottomed depression, the crater, in which there is usually a small lake of liquid lava, giving off gases

freely in little spurts from its surface. For years the lava may slowly rise in the crater, till at length the pressure of the lengthening column causes it to burst a way out somewhere on the flanks of the mountain and flow as a bright stream, spreading widely till it cools. Meantime the level of the lava pool in the crater sinks hundreds of feet. All goes on quietly as a magnificent spectacle, sometimes including a brilliant fountain springing hundreds of feet into the air. The rapidly flowing stream in one case poured over a cliff into the sea as a fiery fall a mile wide. The longest stream recorded came from Mauna Loa and reached a length of sixty miles before cooling and congealing.

Flows of a similar kind occasionally come from long fissures, as at Laki in Iceland, where for a length of twelve miles lava welled out, making a wide level floor and completely occupying a river valley.

It is probable that some of the old basaltic lava plains, covering 200,000 square miles of western Canada and the Columbia region to the south, where few or no cones or craters can be found, were formed in the same way; and the Deccan traps of central India and also the great lava plains of southern Brazil and Uruguay, covering many thousand square miles, are additional illustrations.

Volcanoes with Explosive Eruptions. At the other end of the scale there are very viscid rhyolitic lavas charged with gases which cannot escape easily and quietly, but at last, as they reach the surface where the pressure is diminished, explode violently and fling red-hot materials in all directions. A well-known example of this type of eruption was that of Krakatoa in 1883. This small island in Sunda Straits near Java burst into a terrifying eruption which scattered bombs for twelve miles around, hurled fragments as large as one's fist twenty-five miles, and overwhelmed all the adjoining coasts and plantations with ashes and dust. The finer particles of dust reached the upper air currents and were carried round the world, causing remarkable red sunsets which aroused interest everywhere.

Much of the material flung off consisted of pumice, a variety of lava so filled with air vesicles as to float, and Sunda Straits were for a time blocked with the floating masses, which

FIG. 13. MONT PELÉE

gradually drifted away or were waterlogged and sank. Large pebbles of this pumice thrown up by the waves can still be found on the north shore of Australia, 2000 miles away, and the sea bottom over hundreds of thousands of square miles must be strewn with them. This violent explosion caused a sea wave which did much damage on neighbouring coasts and reached West Australia, 1800 miles distant. In many ways the effects were like those of an earthquake of the usual kind. In a few days the eruption was over and it was found that about a third of the island had been torn to pieces and had disappeared. The amount of rock ejected has been estimated at eighteen cubic kilometres.

The eruption of Mont Pelée on the French island of Martinique in 1902 was of the same type. The steam and gases from the explosions, charged with hot particles, flowed down the mountain-side and in fifteen minutes destroyed the city of St. Pierre with 30,000 people.

No fluid lava came to the surface in this eruption, but after the great explosion a curious obelisk or spine of plastic but very porous lava was pushed up from the crater, at one time reaching 1800 feet in height. It was not a permanent feature but soon crumbled to debris.

Accounts of the recent eruption of Katmai in Alaska put it in the same class with the eruptions mentioned above.

Intermediate Types of Volcanoes. Most volcanoes are of an intermediate type and are built up partly of lava streams and partly of loose materials due to explosion. The best-known and longest-studied volcano in the world, Mount Vesuvius near Naples, may be taken as an example.

Its predecessor, Mount Somma, was thought to be an extinct volcano with a large crater, the whole overgrown with trees or bushes; but in 79 A.D. an explosive eruption took place, destroying with its showers of ashes and red-hot stones two cities near its base, Pompeii and Herculaneum, as recorded by the younger Pliny. On the ruins of Somma Vesuvius was built, and from time to time since then it has been in eruption, lava streams pouring out in various directions and the surrounding towns and vineyards suffering from the fall of ashes and bombs. The size and shape of the crater and the height of the summit have undergone many

changes, and occasionally an inner cone has been built up within the main crater.

The lava given off is not very fluid, moves sluggishly and with constant breaking and rolling over of the hardening black crust formed by cooling. Occasionally this crust grows so strong that the liquid lava within flows on and leaves the shell as a long irregular tunnel. When in moderate eruption great bubbles of lava seem to be raised within the crater till the tension of the steam beneath becomes too great and the bubble bursts, flinging red-hot fragments in all directions.

Photo. by E. S. Moore

FIG. 14. ERUPTION OF NGAURUHOE, NEW ZEALAND, IN 1914

This may go on with much regularity, an explosion about every half-minute. Meantime a tall column of steam rises some thousands of feet and drifts to one side with an upper air current, the form resembling that of an Italian stone pine. At night these explosions and the yellow streams of lava make a brilliant display, and may be seen for sixty miles away on the Mediterranean.

Etna, with its two hundred parasitic cones, has a still longer history, reaching back for more than 2000 years.

Calderas. Since the materials for the eruptions come from beneath, there is a tendency for volcanoes to collapse after cubic miles of molten rock have been removed from

under their foundations by successive eruptions. The whole central part of the mountain may thus sink out of sight, leaving a vast round depression with steep cliffs as walls. Such an arrangement is called a *caldera* (caldron), and in many cases the hollow is occupied by a lake. In other cases it may be somewhat flatly floored, and if the volcano has not become extinct there may be one or more active cones and craters within it.

Crater Lake in southern Oregon, six miles long and four miles wide, enclosed by cliffs 500 to 2000 feet high, is the

FIG. 15. CRATERS AND CINDER CONES, MOUNT ETNA
Eruption of 1892.

best example in North America. A small later cone forms an island in it. Larger examples are found in Italy, such as the beautiful lake of Albano, and the Lago di Bolsena which has diameters of eight and a half and seven and a half miles. One of the largest known is the caldera of Aso in Japan, which is fourteen miles by ten in dimensions and has an active volcano rising from its floor.

SUBMARINE VOLCANOES. Volcanoes are not confined to the land, but may build up mountains from the sea bottom in regions of disturbance. Some of them are known to us only from their conical shape as shown by soundings; but there are numerous examples where the volcano has risen above sea level, forming an island. Graham's island, which appeared

in the Mediterranean near Sicily in 1831, was formed of loose materials and was later washed away, leaving only a shoal. In 1793 a new island rose with great commotion in Alaskan waters, and two others have risen in later years, forming the Bogoslov islands.

The greatest instance of the kind is found in the Hawaiian islands, built up from profound depths in the Pacific almost entirely of volcanic materials. If they stood upon dry land some of their summits, like Mauna Loa, would be the highest mountains in the world. This work was done long before historic times, however.

Distribution of Volcanoes. Volcanoes, as one might expect, are usually found in earthquake regions, so that a map of the one would roughly give the distribution of the other. A great irregular circle of volcanoes, active or extinct, surrounds the Pacific. On the western side they are numerous in Alaska, the Pacific States, Mexico, Central America, and the Andes of South America. Mount Erebus in Antarctica and the New Zealand volcanoes to the south are followed by volcanic islands in the Philippines and Japan on the east, while volcanoes in Kamtchatka and the Kurile and Aleutian Islands finish the girdle of fire about the greatest ocean. Beside this there are volcanoes scattered over the Pacific, some, like those of Hawaii, built up from great depths.

A more scattered row of volcanic islands, beginning with Jan Mayen and Iceland in the north, and including the Azores and Cape Verde islands, runs down the centre of the Atlantic; volcanoes occur also in the Mediterranean, and are very numerous in the East Indian islands; while in the western hemisphere a curved row of volcanic islands occurs in the West Indies.

This distribution along lines of adjustment where mountains are rising or blocks of the sea bottom are sinking is natural, since here only can we imagine the formation of channels by which molten rock can reach the surface.

Causes of Volcanoes. The actual source of the lava is, of course, out of reach in the depths; but from what is known of the rate of increase in temperature with depth one can assume that some miles below the surface the heat would be sufficient to melt ordinary rocks under surface conditions,

One would expect that at a given depth there would be a continuous sheet of molten lava waiting to escape through any opening to the surface. For reasons given earlier, we know that the earth as a whole is extremely rigid, so that no continuous sheet of molten rock can exist a short distance below the surface. In reality the lava supply of volcanoes must come from relatively small local pools. Even close neighbours, like Mauna Loa and Kilauea, only twenty miles apart, must have distinct sources of supply, since the lava of Mauna Loa rises about 10,000 feet higher than that of Kilauea.

Various explanations have been given to account for these local pools of lava. It has been suggested that at a given depth, where the heat should be great enough to melt eruptive rocks, the immense pressure of overlying materials prevents liquefaction, since a rock in melting must expand. Basalt, for example, expands four per cent. when melted.

One might suppose that any relief from pressure, such as the rise of a fold or the tilting of a block of the earth's crust in mountain building, might relieve the layer from pressure at a given point, and allow the potential lava to expand and rise through any opening to form a volcano.

If this explanation is correct, one would expect volcanoes to accompany all great mountain ranges, which is far from being the case. One thousand miles of the main range of the Canadian Rockies consist entirely of sedimentary rocks, and the only eruptions in the range occur at its southern end, where there are some beds of ash and a small area of nepheline rock, but no recognisable volcano. Other areas of recent mountain building show a similar lack of volcanoes, as in the Alps and Himalayas. On the other hand, in some lofty and recent mountain ranges volcanoes are frequent, the Andes being a good illustration.

The mere opening up of a channel, together with relief from pressure of overlying rock, does not account for any large number of volcanoes; but the settling down of large blocks or arcs of the crust is a very frequent cause. This may be seen in the volcanoes along the great African rift, and is probably illustrated by the festoons of volcanic islands on the north and east of the Pacific, as well as in the curve of

volcanic islands in the West Indies. In these cases probably the pressure of the sinking block has aided in forcing lava up round the fractured edges.

Occasionally a volcano or a group of volcanoes rises through what appear to be undisturbed sediments, and some geologists believe that the molten magma can drill its way up without any open fissure, by melting the rocks above or by "stoping" the overlying blocks until the surface is reached.

In addition to the earth's original heat as assumed above, there are other possible sources of heat of a more local nature. The crushing of rocks in mountain building must generate a large amount of heat, which has been suggested as a cause of volcanoes. An unusual accumulation of radioactive material, also, might supply heat enough to melt rocks locally and so cause a volcanic eruption.

It must be admitted that the problems connected with the melting of the lava and its ascent through miles of solid rock to the surface remain quite obscure.

Sources of the Gases of Volcanoes. The gases of volcanoes, especially steam, seem almost as important in eruptions as the lava itself, and many of the phenomena mentioned above are due to the action of the volcanic gases. The source of these volatile constituents of the lava has been much debated and cannot be considered as finally settled.

Some geologists believe that the water given off in vast quantities as steam in most volcanic eruptions is of surface origin, rain or snow water or the water of lakes or the sea, which has settled into the rocks and has been in a sense dissolved by the molten magma. They point to the fact that volcanoes are almost always found near the sea or as islands rising from the sea bottom.

Not all volcanoes, however, are really near the sea or some great lake which might supply water. Some of the finest and loftiest volcanoes in the world, such as Chimborazo, Cotopaxi, and Ollaguë, all reaching 20,000 feet, rise from the vast, dry tableland of the Andes, 10,000 or 12,000 feet above sea level and 150 miles or more from the coast. Ollaguë, in northern Chile, stands in the driest desert in the world. In such cases no surface supply is available, and the ascending lava must have brought its abundant waters from the depths.

Probably most geologists believe that the lavas are originally charged with water or its constituent gases, and with the compounds of sulphur, chlorine, carbon, etc., given off in eruptions. These original gaseous substances dissolved in the molten rock are called "magmatic" or "juvenile." The term magma is used for molten matter occurring in the depths, while the same molten material is called lava when it occurs in a volcano. The word juvenile, which is not so commonly used as magmatic, implies the recent appearance on the surface of these gases or fluids set free from the depths.

Extinction of Volcanoes. Volcanoes may be active for only a few days and then cease their work and become extinct, like Monte Nuovo near Naples; or they may continue active for thousands of years, like Etna, whose history reaches back to 600 B.C., as far as the records go.

Volcanoes may cease their work and become dormant for years or centuries and then break out afresh, as Somma, supposed to be extinct, became transformed into Vesuvius.

Ultimately the supply of lava diminishes and no longer reaches the crater, the last remnant congealing in the channel beneath and sealing the opening.

Active volcanoes have been estimated to number about five hundred, but extinct volcanoes run into the thousands. The only known volcanoes in Canada sufficiently well preserved to display their typical form are extinct: one a small cinder cone with a crater burst by a little lava stream, in the Yukon territory; the other Mount Garibaldi, a fine peak with several lava streams, forty miles north of Vancouver.

Though even extinct volcanoes are rare in Canada, typical volcanic products are widely found in the older geological formations. Lava streams and plains of Cenozoic age occupy much of central British Columbia. A band of white volcanic ash lies just beneath the soil for many miles along the Yukon river. Very ancient lavas (Keewatin) occur in northern Manitoba and in northern Ontario. In the latter province they once covered many thousands of square miles.

Later lavas (Keweenawan) have a thickness of more than 20,000 feet near Lake Superior, and a thick sheet of tuff (volcanic ash) of nearly the same age occurs near the Sudbury nickel mines.

The stumps of old volcanoes (Devonian) make striking hills near Montreal, and volcanic rocks of a much later age (Triassic) form the cliffs of Blomidon in Nova Scotia.

Except for recent feeble activity of Lassen Peak in the far west, the United States has only extinct volcanoes. A majestic row of them, beginning with Mount Baker just south of the British Columbian boundary, runs south into California. For really active volcanoes in North America one must visit Alaska or Mexico. Mount Orizaba, the highest volcano (18,300 feet) in Mexico, is perhaps extinct, since its top and crater are snow covered; but Mount Colima (12,000 feet) and many smaller volcanoes are still active.

FUMAROLES AND HOT SPRINGS

Long after the last eruption of a volcano, steam and certain gases may pass off from the slowly cooling lava beneath the surface. The steam may escape under pressure, forming a fumarole, or, where the lava has cooled farther, only hot water may be given off, forming springs which deposit sinter (mainly silica), often forming beautiful basins.

Probably the most striking development of fumaroles in the world is to be found in the Valley of Ten Thousand Smokes, near the volcano Katmai in Alaska. As no smoke, only vapour of water, is given off, the name seems badly chosen. In this valley an area of some square miles is riddled with openings from which steam escapes.

Hot springs are found in almost all volcanic regions, but they are not confined to them, since waters sinking far enough into the earth may become heated and rise to form springs. A good illustration is to be found in the Banff hot springs in the Rocky Mountains, which are fifty miles from the nearest known eruptive rock.

GEYSERS

While fumaroles and hot springs are common in dying volcanic regions, "geysers," which intermittently spout columns of hot water into the air, are known only in three places: Iceland, where the name originated, New Zealand, and the Yellowstone Park. Years ago a geyser near Rotorua in New

Zealand flung its jet of hot water 1600 feet into the air, but an eruption of the near-by volcano Tarawera interfered with its subterranean channels and put an end to the display.

The Yellowstone Park geyser region is at present much the most extensive and interesting in the world.

The cause of these recurring eruptions of hot water and steam is to be found in the superheating of steam in the lower channels that feed the geyser. The column of cold water in the upper part of the vent presses upon the hot water beneath, raising the boiling point until the temperature is high enough to generate suddenly a great volume of steam which flings the water above as a jet into the air.

The source of the water in hot springs and geysers is probably largely rain and melting snow; but part of the supply may be magmatic in origin. Such hot waters sometimes contain salts of the metals in solution and deposit metallic minerals in the sinter forming their basins.

Probably similar hot waters circulating in fissures far below the surface in the vicinity of masses of cooling eruptive rock deposit ores and other minerals in veins, which may become of importance to the miner in later ages. Most of the ore deposits of the world were formed in this way.

METAMORPHISM

It has been shown that even molten rock contains water or other volatile substances in important amounts, and this is commonly true also of the sedimentary rocks, most of which were formed beneath the sea. Water is the medium through which most chemical reactions take place; hot water is a better solvent than cold water; and pressure has been proved to increase the activity of water. Where rocks, whether eruptive or sedimentary, are exposed to the action of hot water under pressure, changes may be expected; but magmatic waters coming from hot eruptive rocks, charged with silica and other substances in solution, will be most effective in this respect.

Rocks may be exposed to these conditions simply because they are at great depths, or because eruptives have penetrated to beds at higher levels. Frequently both depth and eruptive

magmas may be at work. The effect of heat, pressure, and water containing various substances in solution in attacking the minerals of rocks and transforming them into other minerals is called *metamorphism.* This may imply only a rearrangement of elements already present or the removal of some elements with the introduction of others.

Sometimes a distinction is made between *contact metamorphism,* due to the presence of a cooling eruptive sheet or mass near by, and *regional metamorphism,* where the changes take place on a large scale and usually at a greater depth; but there is no sharp boundary between the two processes. Metamorphism is greatly helped by crushing and shearing in connection with mountain building, since this gives easy access for fluids, and where mechanical work of this kind is important the term *dynamic metamorphism* is sometimes used.

Effects of Metamorphism on Sedimentary Rocks. The usual sedimentary rocks, shale, sandstone, and limestone, are quite differently affected by metamorphism and should be taken up separately.

Shale, which is merely consolidated clay, is changed into slate by pressure and shearing with a small amount of recrystallisation. In the harder slates, like those used for roofing, many small scales of mica or chlorite may be seen in thin sections and much of the muddy material has been changed into definite minerals. In contact metamorphism certain compounds of silica and alumina are apt to form, such as staurolite, a hydrous silicate of iron, alumina, and magnesia, or andalusite or sillimanite or cyanite, silicates of alumina. A more complete recrystallisation will give rise to phyllite with a shimmering surface due to the formation of sericite; and finally the whole of the materials may be rearranged into quartz and mica, forming mica schist, or into quartz, feldspar, and mica, forming gneiss. Often garnets and other crystalline minerals are formed at the same time.

Sandstones are differently acted on according to their composition, pure quartz sands being merely cemented by the outgrowth of the quartz grains till the whole becomes a mass of solid quartz, called quartzite. Argillaceous sands turn to mica schist; and arkoses, or sandstones with much feldspar, become gneisses undistinguishable from some metamorphosed shales.

Limestones and dolomites, if pure, are simply rearranged into crystalline calcite or dolomite, forming marble. If impure a great variety of minerals may result, including micas, varieties of hornblende or augite, graphite, etc.

Coal loses its volatile matter, changing first to anthracite, which except for ash is nearly pure carbon, and afterwards to graphite.

The metamorphism of tuffs or ash rocks depends mainly on the composition of the materials, and results in sericite or mica schists or gneisses for the acid rocks, and in chlorite or hornblende schists for the ordinary basic rocks. Massive eruptives are less attacked, unless they have been crushed and sheared, when results like those just mentioned will be produced. Very basic rocks like peridotites are transformed by hydration into serpentine or talc; but many authorities would include this change in weathering rather than in metamorphism.

EPIGENE FORCES

WEATHERING

The epigene forces, as noted earlier, are those which are derived mainly from the sun and perform their work on or near the surface of the earth. They are familiar to us, since they are in operation all around, and on that account pass almost unnoticed. Their ceaseless activities are constantly moulding the land and giving it the contours of plain and valley, hill and mountain, that meet our eyes everywhere, but the work usually goes on so slowly as to be quite overlooked.

Beginning with a world whose outer crust is of solid rock, the first operation to be studied is naturally that of the crumbling and decay of rocks, sometimes expressed as the effects of the "tooth of time." The most important agents in this work are water, the gases of the air or of the soil, and changes of temperature, all commonplace and unimpressive in their action, yet capable of destroying in time the most resistant rocks.

Water is present everywhere as a variable constituent of the

air, and falls as rain or snow, changing from the gaseous to the liquid or solid state; and pure water can dissolve salt or gypsum, which are rarely found on that account except in deserts. The oxygen of the air is a powerful chemical agent. Carbon dioxide is found in small quantities in the air, about 4 parts in 10,000, and in larger amounts in soils where organic matter is decaying. Heat expands and cold contracts, tending to destroy the cohesion of rocks and to split off fragments. The combined effect of these agents is weathering.

Oxidation. Many eruptive rocks contain compounds not completely oxidised, one of the commonest being ferrous oxide, which forms part of most of the green minerals, such as augite or hornblende. Oxygen in the presence of moisture tends to combine with the ferrous oxide to form the more oxidised compound ferric oxide, which is red, or if hydrated, brown, so that the work of oxidation destroys the mineral attacked and forms limonite. This type of weathering causes rocks like basalt or diorite to change their colour from green or black to brown, and so weakens them that they are softer and more easily attacked by other forces. The change in colour of blue clay, which weathers brown, illustrates the same effect.

Carbon Dioxide. The most effective reagent in weathering is carbonic acid, the combination of carbon dioxide with water, which is only feebly acid, but slowly dissolves certain minerals and decomposes others. One of the most important sedimentary rocks is limestone, formed of calcite or carbonate of lime, which is soluble in carbonic acid. All exposed limestones and marbles are being dissolved and carried down to the sea as a result of this action, and almost all spring and well waters are charged with lime. The effects are well shown in cemeteries, where marble monuments a few years old lose their polish and begin to crumble, especially on the side toward the rainy winds. In fifty years the inscription is generally illegible. Dolomites are much more slowly attacked.

Among the eruptive and schistose rocks, certain feldspars of great importance, such as orthoclase and the soda plagioclases, are attacked by carbonic acid which decomposes the feldspar into a soluble silicate of potash or soda, and an insoluble silicate of alumina, which is left behind in the

hydrated form as kaolin or clay. Since the feldspars make the bulk of most eruptive rocks and gneisses, this completely disintegrates them, leaving a crumbling sand instead of a solid resistant rock. Several other silicates are attacked in a similar way.

This process is comparatively slow, and its results are not yet very apparent in the glaciated regions of Canada and the northern United States, but are well displayed in granite

FIG. 16. HONEYCOMB WEATHERING IN STRATIFIED ROCKS, LAKE TIMISKAMING, QUEBEC

regions never covered by the ice, for instance at Washington, D.C., in Brazil, or in the Klondike.

Change of Temperature. The lighting of a fire on bare rock often splits off thin slabs by the rapid expansion of the part immediately beneath. The farmer sometimes uses fire setting followed by a dash of cold water to break up boulders in his fields; and before the days of explosives this was the best method of breaking down rock in mining. There is no doubt that the ordinary changes of temperature have a similar effect, though they act much more slowly. In desert regions, where the dry atmosphere permits rapid radiation of heat at night, the extreme temperatures of day and night may even

FIG. 17. TALUS FORMED BY ACTION OF FROST, NIPIGON RIVER, ONTARIO

range from 150° F. to the freezing point, and slices and fragments of rock are constantly being split off from exposed rocks, which are gradually buried under the chips due to their own decay.

In climates like ours, however, frost is the great quarryman, heaping a pile of blocks called a *talus* at the foot of every cliff. The fragments broken off expose fresh surfaces for the work of weathering which greatly aids the process.

Rain Action. In most parts of the world rain falls frequently. Even in deserts violent rain sometimes falls, perhaps, however, only after the lapse of years. In the nitrate region of northern Chile it is said that the last rain fell sixty-five years ago, yet the superficial effects of rain erosion may sometimes be seen there.

A single drop of rain exerts a most insignificant force for geological work, but the cumulative effects of the drops in a storm may be important. About thirty inches of rain fall in the year in Ontario, having a weight of 2,200,000 tons per square mile. In sum, then, the force exerted by the falling drops is very important. The gullying of hilly fields after a heavy shower and the muddy waters of the overflowing streams give evidence that a powerful force has been at work.

More striking illustrations are supplied by the earth pillars frequently seen in mountain valleys. These are carved by rain from boulder clay. The clay is readily removed where unprotected, but where some boulder occurs as a cap the washing away of the surrounding clay leaves a pillar. There may be dozens of such pillars, each sheltering under its stone. If the stone is dislodged the pillar becomes a cone and soon wastes away.

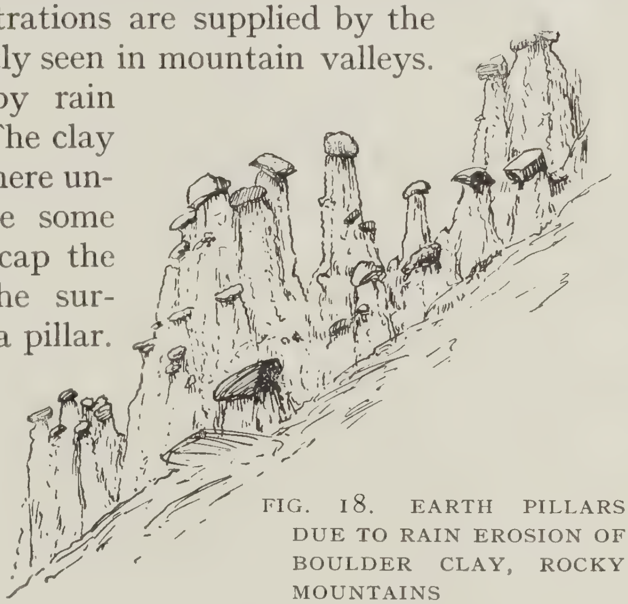

FIG. 18. EARTH PILLARS DUE TO RAIN EROSION OF BOULDER CLAY, ROCKY MOUNTAINS

Earth pillars are often twenty-five or thirty feet high, and serve as monuments to rain action. In the long run cubic

miles of clay are removed by rain from the sides of valleys like that of Bow river and swept down to the river itself.

Part of the rainfall runs off quickly to the nearest stream; this is sometimes called the run-off; and part sinks into the ground. On rock surfaces almost the whole of the rain flows off directly. On sand or gravel almost the whole sinks in and is lost to sight. The types of work performed by these two divisions of the rainfall differ greatly, though ultimately, perhaps after months or years of underground wandering, the part that disappears into the soil usually reappears as springs and joins the regular circulation of the streams.

GROUND WATER

The spaces between the particles of soil or of porous rocks are very small, sometimes only capillary, and the water

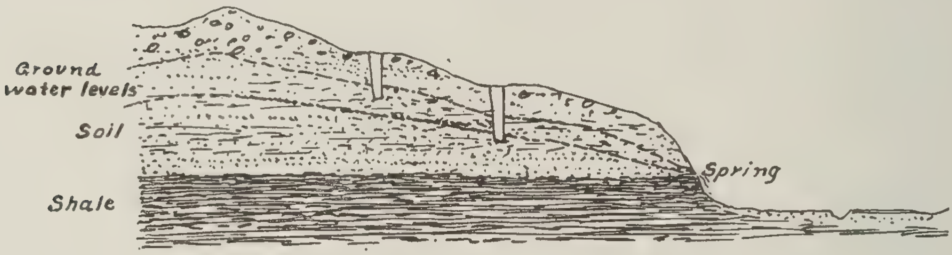

FIG. 19. UNDERGROUND WATERS

Water from rain and melting snow sinks into the soil until arrested by some impermeable bed, such as clay or shale. The level of ground water rises after a wet season and sinks after a dry one, leaving shallow wells without a water supply. Springs occur along the sides of slopes where the top of the impermeable layer is exposed.

soaking in can move only slowly; nevertheless as "ground water" it is constantly urged downwards by gravity and makes its way just above some impermeable layer toward the lowest point, where it may emerge as a spring. The level of ground water varies with the season, being highest as a rule in spring, when the ground has been soaked with rain and melting snow, and lowest after the droughts of summer. In the country parts of Canada the water supply comes sometimes from springs but more often from wells, both dependent on ground waters. A well, if not deep enough, may fail toward the end of summer because of the sinking of the ground water, and not all springs are perennial.

Since the ground waters in their slow motion underground

generally dissolve lime by the aid of carbonic acid and also obtain small amounts of gypsum (calcium sulphate) and of salt (sodium chloride), well and spring waters are generally "hard," that is, contain compounds of lime. This is noticed in washing, when the fatty acids of the soap combine with the lime, giving a "curdiness" to the water, and also in the "furring" of the tea-kettle, where the boiling away of the water and the driving off of carbon dioxide make a coating of carbonate and sulphate of lime. The salts and gases dissolved in such waters give them a more pleasant flavour than the purer but more insipid rainwater with which they began. Not infrequently a little sulphate of iron has been picked

FIG. 20. LANDSLIP, FRANK, ALBERTA

up also, giving a slight inky taste to which one presently gets accustomed.

LANDSLIPS. The soaking of rain into the ground may so far soften beds of clay or silt or fine sand that they can no longer support the load above, and large slices or even square miles of loose deposits may slip on such a lubricated layer into the nearest valley. Such a movement is called a landslip or landslide, and is illustrated along clay cliffs almost every spring. Destructive landslides have occurred at several points in the province of Quebec, as at St. Albans in 1890, when an area of clay and sand $2\frac{1}{2}$ miles long, 1 mile wide, and from 10 to 250 feet thick slid down into the valley of St. Anne river, destroying farms and houses.

The most serious landslip recorded in Canada is that which occurred at the coal-mining town of Frank in Alberta, on July 4, 1903, when a large part of the top of Turtle Mountain slid into the valley, running right across it and rising 400 feet

on the other side. It is estimated that 80,000,000 tons of limestone were thus spread out for nearly two miles across the valley, destroying part of the town and burying the Crowsnest railway for some distance. It is probable that the work of frost in fissures on the mountain top was mainly responsible for this disaster.

Much more extensive landslips have taken place in the Alps, as that of Rossberg which buried several villages, and in the foothills of the Himalayas, where a landslip dammed back a tributary of the Ganges, forming a large temporary lake.

Artesian Waters. In some places surface waters find their way into porous beds, generally of sand or sandstone, called *aquafers*, between impermeable beds of clay or shale, and in this way may travel long distances and reach great depths where they may become warm or even hot. If some region of faulting provides fissures by which they can reach the surface, as at Banff, copious hot springs result. Where there is no such natural outlet the drilling of a well may give escape to the water, if there is sufficient slope to provide a "head," and there may be a permanent flow of *artesian water*. Such supplies may be tapped in desert regions, hundreds of miles from their source in some range of mountains which gathers the rain clouds by reason of its elevation. Parts of Australia and some of the Saharan regions have important supplies of water drawn from artesian sources.

Mineral Springs. While all spring waters contain mineral matters such as lime, gypsum, and salt in solution, the name "mineral spring" is given only to those containing less usual ingredients. They may be sulphur springs containing hydrogen sulphide, chalybeate springs strongly charged with iron compounds, saline springs containing various salts in solution, etc. Mineral springs are often of medicinal value, as at Banff, Alberta, and at Caledonia, Preston, and St. Catharines in Ontario. Some mineral springs, such as those of Saratoga, New York, and of Carlsbad in Bohemia, have been explained as consisting of magmatic or "juvenile" waters coming from deep-seated eruptives, instead of surface waters which have ascended after reaching a great depth.

Caves. In limestone regions waters containing carbon

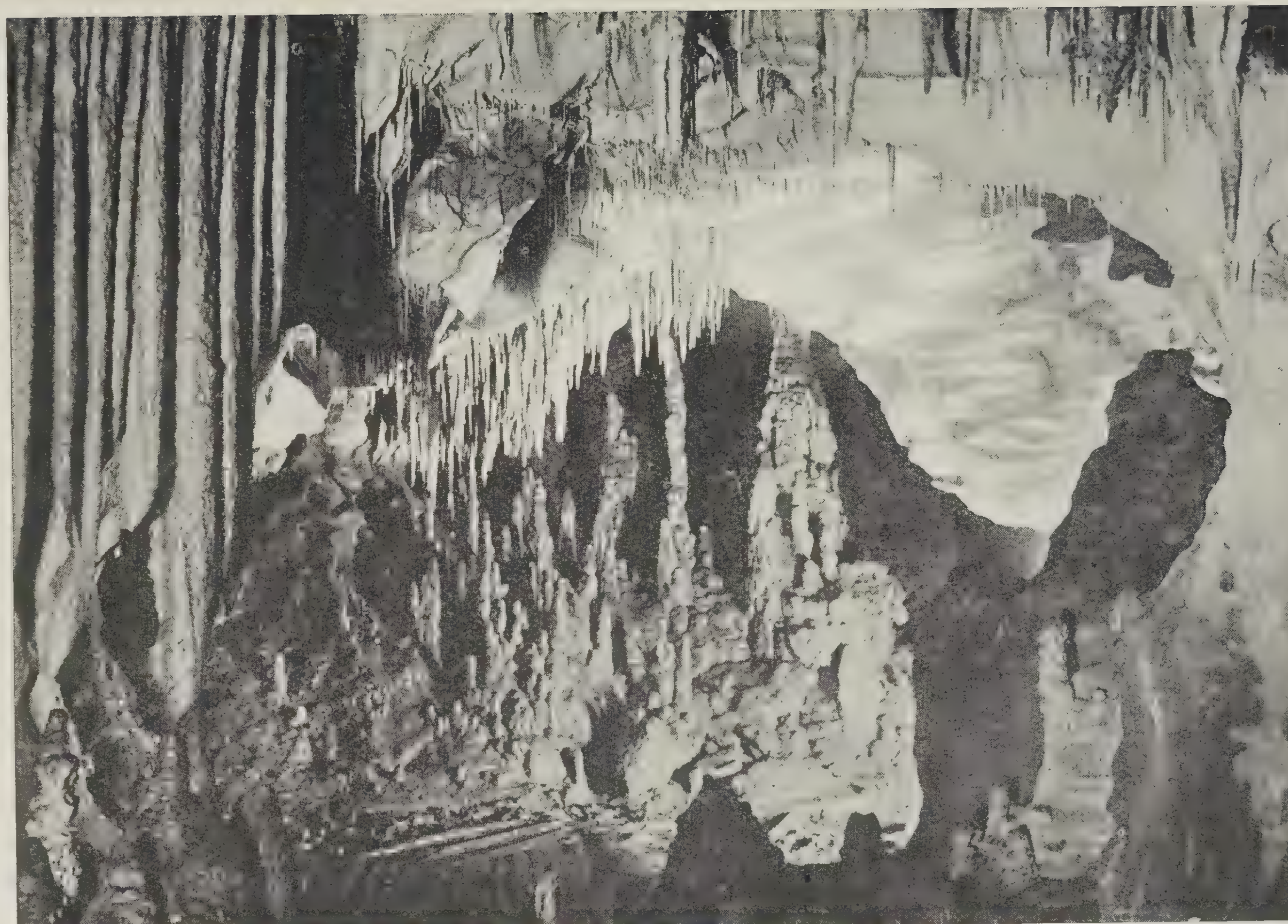

FIG. 21. CAVE, NEW ZEALAND

dioxide may follow joint fissures or other small openings and slowly dissolve out underground channels, which may ultimately be widened and deepened into great caverns sometimes running for a number of miles, commonly with a small stream or even a river flowing through them. There may be wide and lofty chambers wonderfully decorated with *stalactites* hung from above or *stalagmites* growing up from the floor. These structures are of lime deposited where drops of water continually drip from fissures in the limestone roof. The carbon dioxide escapes in the open air of the cave, and the lime in solution must therefore be deposited.

The most striking caverns known in Canada are the Namiku Caves or Caves of Cheops on Cougar Creek, west of Glacier in the Selkirks. More famous caves are found in other countries, such as the Mammoth Cave in Kentucky, through which one can walk for a number of miles. There are some limestone regions, like the Karst in southern Austria, where the whole drainage is underground, and where the rivers are quite hidden except where some cavern roof has collapsed, forming a sink hole.

THE WORK OF RUNNING WATER

The most active of the epigene agencies is running water, which works almost everywhere on land surfaces, except where it is replaced by the solid form, ice. In most deserts, even, there is an occasional powerful flow of temporary streams resulting from some sudden downpour; while in all ordinary regions water flows permanently as brooks or creeks or rivers, fed by rains and melting snows or springs or glacier ice. The word "brook" has practically gone out of use in central and western Canada, "creek" taking its place. The distinction between creeks and rivers is very indefinite, the small, easily-waded stream of the Don at Toronto being called a river in Ontario, while the Kicking Horse, with a volume of water like the Ottawa, is merely a creek in British Columbia.

The work of running water includes the transport of materials, the cutting down of its bed, and finally, the deposit of the materials transported. Fragments of rock lose from a third to two-fifths of their weight in the water, which greatly

aids transport. The work of transport and abrasion depends on the rate of motion of a stream, and that depends on the volume of water and the grade of its channel. Friction on its bed counts for far more with a small stream than a large one, so that a few inches of slope to the mile suffice to keep a large river like the Nile or the Mississippi moving four or five miles an hour, while a small brook may need a slope of several feet per mile to cause the same rate of flow.

The part of the rainfall which flows off immediately gathers into temporary rills which combine with others and presently join some permanent stream; while permanent streams (creeks or rivers) generally receive a part of their supply from springs or lakes or the melting ice of some glacier.

WATERSHEDS AND CATCHMENT BASINS. Each river has its own territory, draining all the water precipitated upon it except the portion removed by evaporation; and the whole of Canada has been divided up into drainage systems, tributary usually to some great river which carries its waters to the sea. The amount of water which a river can deliver, say for a city water supply or as a source of power at some waterfall, will equal the rain and snowfall of the region minus the evaporation; and in estimating the continuous supply available, one should take the amount of flow at the stage of lowest water. The boundaries of these *catchment basins* or drainage areas form *watersheds*, sometimes called *divides* or *heights of land.*

Watersheds vary greatly in their character, being sometimes low and swampy, or even a lake which has an outlet both ways, while, on the other hand, a sharp mountain ridge may decide whether a raindrop shall go to the Atlantic or the Pacific. One of the most notable divides in the world extends along the southern Rockies between Alberta and British Columbia, where tributaries of the Missouri, the Saskatchewan, the Mackenzie, the Columbia, and the Fraser rivers head not far apart, sending their waters to the Gulf of Mexico, Hudson bay, the Arctic ocean, and the Pacific ocean. One small pool, the Committee's Punch Bowl, on Athabasca pass, sends a rivulet to the Columbia and another to the Mackenzie, dividing its waters between the Pacific in Lat. 46° and the Arctic ocean in Lat. 68°. The Columbia

snowfield feeds glacial streams whose waters reach the Pacific, the Arctic, and the Atlantic oceans.

Where the headwaters of two rivers flowing in opposite directions meet at a watershed, one of them may have a steeper grade and a larger rainfall and so cut back faster than the other, encroaching on its drainage basin and finally "decapitating" it, thus taking possession of its upper valleys and tributaries. This operation is sometimes called "piracy." The headwaters of the Columbia illustrate this.

Transporting Power of Rivers. The power of rivers to transport materials varies as the sixth power of their velocity, so that a rate of flow of half a mile an hour can transport only sand grains, while at a mile an hour small pebbles can be rolled along, and at two miles angular stones as large as eggs. At more rapid rates large pebbles or stones can be toppled over by the current and thus be moved slowly down-stream. With one's head under water the stones can be heard striking one another.

Angular stones thus moved along the bottom have their edges broken off and presently become rounded pebbles, and the pebbles grow smaller by the constant wear as they advance down-stream. It is evident that the rocks forming the bed of a swiftly flowing river, and especially of a mountain torrent, will be constantly abraded by the rock fragments urged along by the current. This cutting of the bed is called "corrasion." Clear water alone does no work, since it is without tools for the purpose; and streams carrying only fine particles, like silt and sand, may polish the rock beneath but cut down their bed only slightly.

The fragments of stone moved along the bottom of a stream or carried in suspension are called its *load*, and with a given rate of flow only a fixed amount of load can be transported. If a fully loaded stream reaches a wide part of its channel with a gentler grade and the current slackens, some of its load must be dropped. At such points its bed will not be cut down, but will be filled up, and the stream is said to *aggrade* its channel, while in other places it is *degrading* it.

Types of Work done by Rivers. In many rivers flowing from mountains to the sea one can distinguish a swift upper part with a steep grade, an intermediate part with gentler

but irregular grades, and a part flowing through a flood plain nearly at sea level. In the first part cutting and transport are active and deep V-shaped valleys or even steep walled canyons are being carved. Where there are eddies, stones may be kept revolving as grinding tools and pot-holes may result. In low-water seasons one may see the smoothly rounded stones lying at the bottom of deep beautifully shaped wells in solid rock. Pot-hole may succeed pot-hole; the walls between may be broken through and thus the channel is

FIG. 22. CANYON OF ABITIBI RIVER, ONTARIO

deepened fifteen or twenty feet. Pot-holes may be studied along the Ottawa and other Ontario rivers.

Canyons, deep and long gorges cut with steep or nearly vertical walls of rock, are scarcely found in the inhabited part of eastern Canada, but are well displayed in the western mountains, as along Thompson and Fraser rivers. The most famous canyon in the world, that of the Colorado river, is more than 300 miles long and in places more than 5000 feet deep, and has been sawn through a slowly rising tableland which is 7000 feet above the sea.

In its intermediate part the river may be cutting in some places and filling in others, thus adjusting its grade.

In the flood-plain region, as the name suggests, the grade is very gentle, the current slow, and in seasons of heavy rain

or melting snow the river may overflow its channel and spread out over the lowlands. As it spreads out the current slackens, and the mud which is being carried is deposited most thickly on the banks of the river, but to a less extent in the shallow lagoons on each side. This means that the floor of the wide valley or plain is being slowly built up with finely ground materials brought from above.

Since flood plains often supply rich soils and are thickly peopled, the behaviour of rivers under these conditions

FIG. 23. MEANDERS IN FLOOD PLAIN, DON RIVER, TORONTO, ONTARIO

becomes of great practical importance, as in the Mississippi valley. To prevent the damage done by floods, levees (embankments) are built to keep the high water within the regular channel, but when the flood slackens the mud which would have been deposited on the plain is left on the floor of the channel, raising it from year to year until some greater flood than usual breaks the levees and inundates thousands of acres. In northern Italy dikes or levees along the lower reaches of the Po have been raised so high that the surface of the river is above the roofs of the neighbouring villages.

MEANDERS. The flood plains are slowly rising by the addition of layer after layer of mud or silt, but the formation of meanders tends, in the long run, to lower them. The river

Meander in Asia Minor was famous with the Greeks for its crooked channel and has given its name to the windings of all rivers in their flood plains.

If a straight channel is dug through the alluvial deposits of the plain for the use of the river, some obstruction, such as a boulder or an undermined tree, deflects the current a little toward one side, and there the bank is attacked and rapidly carved away. Below this the current is now directed against the other bank, with the same effect, and in the eddy on the inner side of the bend mud and sand are being built up into bars which are dry at low water.

This is an endless process, so that the curves grow more and more extravagant until oxbow bends may come within a short distance of one another. In the meantime the length of the channel grows as the wriggling increases, and the slope per mile grows less proportionately until an unusual flood breaks across at some narrow neck between bends and an "oxbow" is cut off, thus shortening the channel once more. In this process a river may swing from one side to another of its valley, lowering the whole width of the floor, usually leaving on one or both sides a remnant of the former flood plain as a terrace. This is called *lateral planation*, and in course of time the plain is reduced more and more nearly to sea level by the shifting of the meanders.

Deltas and Estuaries. The final destination of the river-borne mud, silt, or sand is the sea or some inland lake. As the flow of the river ceases when it enters the sea, the solids brought with it are deposited, the work being aided by the coagulating power of the salts of the sea; and a bar grows up at its mouth if the sea is not too stormy or strongly tidal. From time to time the river bursts a way through the bar and begins a new one farther out, and so an amphibious region is built out into the shallow water, gradually expanding and often traversed by several channels or distributaries. The flat islands thus formed are roughly triangular, like the Δ (delta) of the Greeks, and the name *delta*, given to these structures at the mouth of the Nile, is now generally used.

There are small deltas at the mouth of many rivers in Canada, as that of the Kaministiquia at Fort William, or of the Fraser at Westminster; and one very large, but

unfortunately useless one, where the Mackenzie river enters the Arctic ocean.

The greatest and most carefully studied delta of North America is that of the Mississippi, which covers 12,300 square miles and has a thickness of 630 feet at New Orleans. It is constantly growing, since the river carries down solids enough in a year to build up a square mile of sea bottom 268 feet.

Where a river enters a stormy or strongly tidal sea, the load it delivers is quickly removed and spread out on the sea bottom so that no delta is formed. Instead there is a funnel-

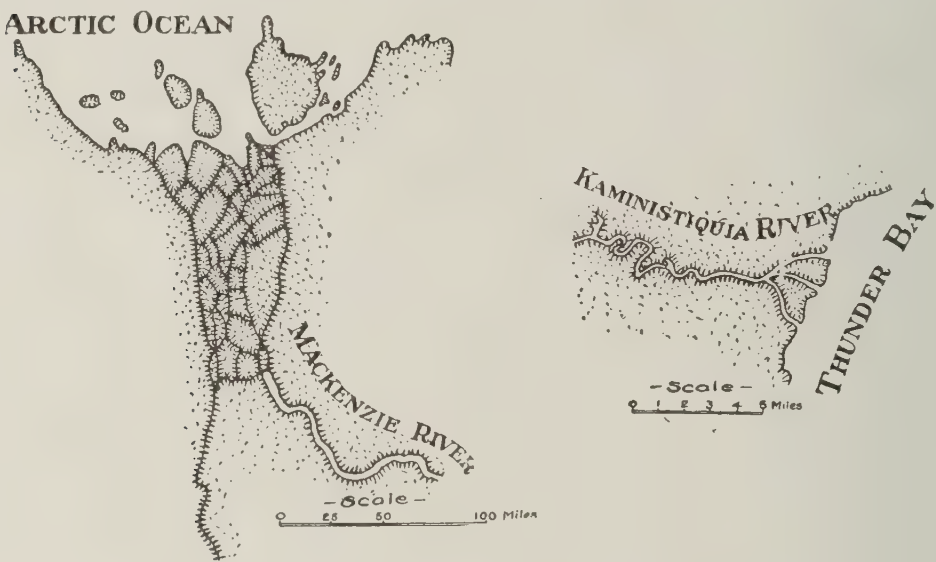

FIG. 24. DELTA OF THE MACKENZIE RIVER, ARCTIC OCEAN, AND OF THE KAMINISTIQUIA RIVER, THUNDER BAY, LAKE SUPERIOR

shaped opening called an *estuary* where the tides boil in and out, scouring the channel clean. Many seaports are formed in this way, especially round the coasts of England. Ports in New Brunswick and Nova Scotia along the Bay of Fundy are largely of this type.

Features of Youthful Rivers. An old river has had time to grade its channel, forming a gradually steepening curve from its mouth at sea level to its headwaters in some mountain torrent; but young rivers have not, and show many irregularities because of the lack of adjustment. These accidental features include falls and rapids and lake basins. Practically all Canadian rivers except the Yukon, which is only partly Canadian, have a very youthful aspect, since the

FIG. 25. EMPEROR FALLS, MOUNT ROBSON, BRITISH COLUMBIA

work of the Ice Age blocked the old channels and forced the drainage into new routes when the ice sheets were thawed away. As a result our rivers have accidental channels, often mere spillways from basin to basin, and there are falls and rapids on almost all of them. Both of these youthful features, lakes and falls, are of great practical importance to the country.

Given time enough and rock fragments as tools, falls are worn away and transformed into rapids, rapids lengthen out and grow less steep, and ultimately a uniform grade is reached. In the case of lakes, deltas may be built out into them and ultimately the basin may be filled, leaving only a marsh; or the outlet may be cut down, partially draining the basin, so that lakes also are ephemeral features of a river system.

THE ST. LAWRENCE—A YOUTHFUL RIVER SYSTEM

The Great Lakes with their connecting rivers ending in the St. Lawrence provide a typical example of a youthful river system. At its head is Lake Nipigon, 850 feet above the sea, connected with Lake Superior by Nipigon river with fine rapids and falls. Lake Superior, the largest area of fresh water in the world, is 601 feet above the sea and is drained by St. Mary's river into Lake Huron with a descent of 22 or 23 feet, of which 18 occur at the rapids of Sault Ste. Marie. Lake Huron is joined to Lake Erie by the St. Clair and Detroit rivers, having only a slight fall. Niagara river connects Lake Erie (575 feet) with Lake Ontario (246 feet) and includes miles of quiet water, tremendous rapids, and the Falls of Niagara, having a vertical drop of 160 feet.

Niagara Falls has some unique features. It has lasted as a vertical fall for thousands of years, beginning at the escarpment near Queenston and cutting its way back six and a half miles to its present position. The reason for this is found in the character of the rocks of the escarpment, hard dolomitic limestone on top and mainly soft shale beneath. The shale is easily attacked by the eddying waters and is undercut. From time to time blocks of the overlying limestone are undermined and fall, to be whirled as missiles against the shale beneath, helping on the work of recession.

FIG. 26. MOUNTAIN TORRENT, NAKVAK, LABRADOR

From Lake Ontario the St. Lawrence flows with many rapids and a total fall of 246 feet to the Gulf of St. Lawrence.

All of the Great Lakes except Lake Erie reach depths below sea level, so that they never can be drained by cutting down their outlets, and the rivers flowing into them bear little sediment, so that the process of filling them with delta materials would be enormously long. From the human point of view the system is very permanent.

The Great Lakes and the rivers joining them have had a powerful influence on the life of the adjoining regions. The lakes with their connecting canals permit navigation to the heart of North America, while the falls and rapids on the rivers furnish power to all the cities within reach. A scarcely noticeable part of the water of Niagara Falls supplies Buffalo, Toronto, and a dozen smaller cities with light and power; and a new installation utilising a fall of 300 feet will soon almost double the amount of power available.

Many other Canadian rivers have similar conditions, though on a smaller scale. The youthful character of the rivers of a country is evidently a matter of great economic importance.

It is perhaps worthy of note that each section of river linking two of the lakes has a separate name, as the Nipigon, the St. Marys, etc., though the whole chain makes up a single drainage system, that of the St. Lawrence. The Mackenzie and the Nelson also change their names above lakes on their course.

Peneplanation. Rivers and their tributaries are continually cutting down their valleys toward base level, and as a result the hills or mountains forming the watersheds are slowly lowered, the grades becoming more and more reduced even at the headwaters, and the country becoming approximately level with only gentle elevations between the drainage areas of the sluggish rivers. If the process were carried to the end a real plain might result, but so far as known this stage has never been reached. The nearly level surface attained, with only slight slopes and low hills or ridges, has been called a *peneplain* (almost plain).

Peneplains mean, of course, that the region has remained stationary for an immense length of time, since any rising or sinking of the land as compared with sea level would interrupt

the process. An important rise of the land would rejuvenate all the rivers, which would begin a new "cycle of erosion" and start the work of destruction all over again.

It is believed that the Pre-cambrian region of Ontario and Quebec is an example of a peneplain which has been elevated, so that all the rivers flowing outwards have many waterfalls and a descent of hundreds of feet on their way to Lake Superior or the St. Lawrence. The region is not now level, but is made up of low hills and shallow valleys. Looking out from a hill top one usually sees that all the hills in sight rise

FIG. 27. WAVES, NEWCASTLE, NEW SOUTH WALES

to the same flat skyline, that of the original peneplain. A rare residual hill rising distinctly above the rest because it resisted erosion better is called a *monadnock*, from a mountain of that kind in the eastern United States.

THE WORK OF SEAS AND LAKES

In standing water, work of geological importance may be done in three ways—by waves, currents, and tides; but in the smaller bodies, such as lakes, only waves are of much consequence.

Destructive Work of Waves. Waves are undulations of the water caused by wind, and as these undulations do

not usually go to great depths, their effects are noticeable only in shallow water and on the shore. As a wave approaches the shore its lower part is hampered in its motion and the upper part tends to topple over as a breaker. The dashing of breakers is a powerful mode of attack resulting in destruction of the shore, forming a cliff where the land is high and removing and assorting the debris to form a beach. Coarser fragments are piled up near the foot of the cliff, while the undertow of

Photo. by Professor Clarkson

FIG. 28. WAVE EROSION, CAPE BLOMIDON, NOVA SCOTIA

the wave by which the water dashed up, returns to its proper level, drags sand and mud back with it, distributing them on the bottom. Since waves rarely strike the shore squarely, but usually at an angle, the materials of the beach will be shifted along shore in the direction toward which the wind is blowing. For example, where the effective storm winds come from the east the beach materials will slowly march westwards.

The destruction of the shore is largely effected by the undercutting of cliffs, slices slipping down from time to time and the materials being worked over by the waves as sug-

gested above. This means the recession of promontories under wave action. The cliffs at Scarboro near Toronto are receding at an average rate of 1·62 feet per annum; and on the stormy coasts of England the shore has in places receded for hundreds of yards or even miles within historic times.

Constructive Work of Waves. On the other hand, the gravel and sand urged along shore by waves from the direction of the prevalent storm winds are built out into the next bay, forming a spit. If the bay is shallow the spit may

FIG. 29. A HOOK. THE "ISLAND" AT TORONTO, ONTARIO

gradually extend across its mouth, forming a bar, perhaps completely cutting it off as a separate body of water. This is shown at Hamilton bay at the western end of Lake Ontario, which is enclosed by the bar called Burlington Beach. Where the bay is deep the spit extends only as far as shallow water will permit and then bends inwards as a hook. In time hook after hook will be built into the deeper water, perhaps forming a considerable area of land with unfilled lagoons between the separate advances. Toronto island is a good example of this. Either a bar or a hook may enclose a well-sheltered harbour and serve as the starting-point for a city.

The new land built by the waves can never rise higher than wave-work permits, on Lake Ontario about five feet above

water level, and often much larger areas, called shoals, remain under water.

The general effect of waves is to smooth out the irregularities of shores, cutting off promontories, and stretching bars across bays. This is well seen on the shores of Prince Edward island and in other regions on the Atlantic coast. A shore is said to be young when its outline is ragged, and old when wave-work is nearly complete.

A change of level may transform an old shore into a young one, as along our Atlantic coast where the land rose after the Ice Age. Depression often provides harbours, like that of Sydney in Australia.

Ocean Currents. Currents in lakes are not of much geological importance, but ocean currents may have much significance, especially as affecting climates and the geological forces depending on climate.

The most important currents are caused mainly by prevalent winds, particularly the steadiest of all winds, the trades. As these north-easterly and south-easterly winds constantly urge the waters of tropical seas westwards, a surface drift is set up in that direction. In the case of the Atlantic this drift impinges on the north coast of South America and is bent north-westwards into the Caribbean sea and then into the Gulf of Mexico, where the waters are entrapped. After doubling back to the south-east the waters escape as a well-marked current, "a river in the ocean," round the end of Florida, and follow the coast to Cape Hatteras. From this point the warm water of the Gulf Stream spreads out over the surface and loses the character of a definite current, but gradually makes its way north-east across the Atlantic as a surface drift. Part of the water turns southwards, completing the circle round the vast eddy of the Sargasso sea, part moves northwards along the European coast, reaching the Arctic ocean and even touching north-western Russia. Iceland feels its effects and a tongue touches the south-west side of Greenland.

On the other hand, a return current of icy water laden with bergs comes down from Davis strait along the coast of Labrador to Newfoundland and bends westwards past Nova Scotia to New England.

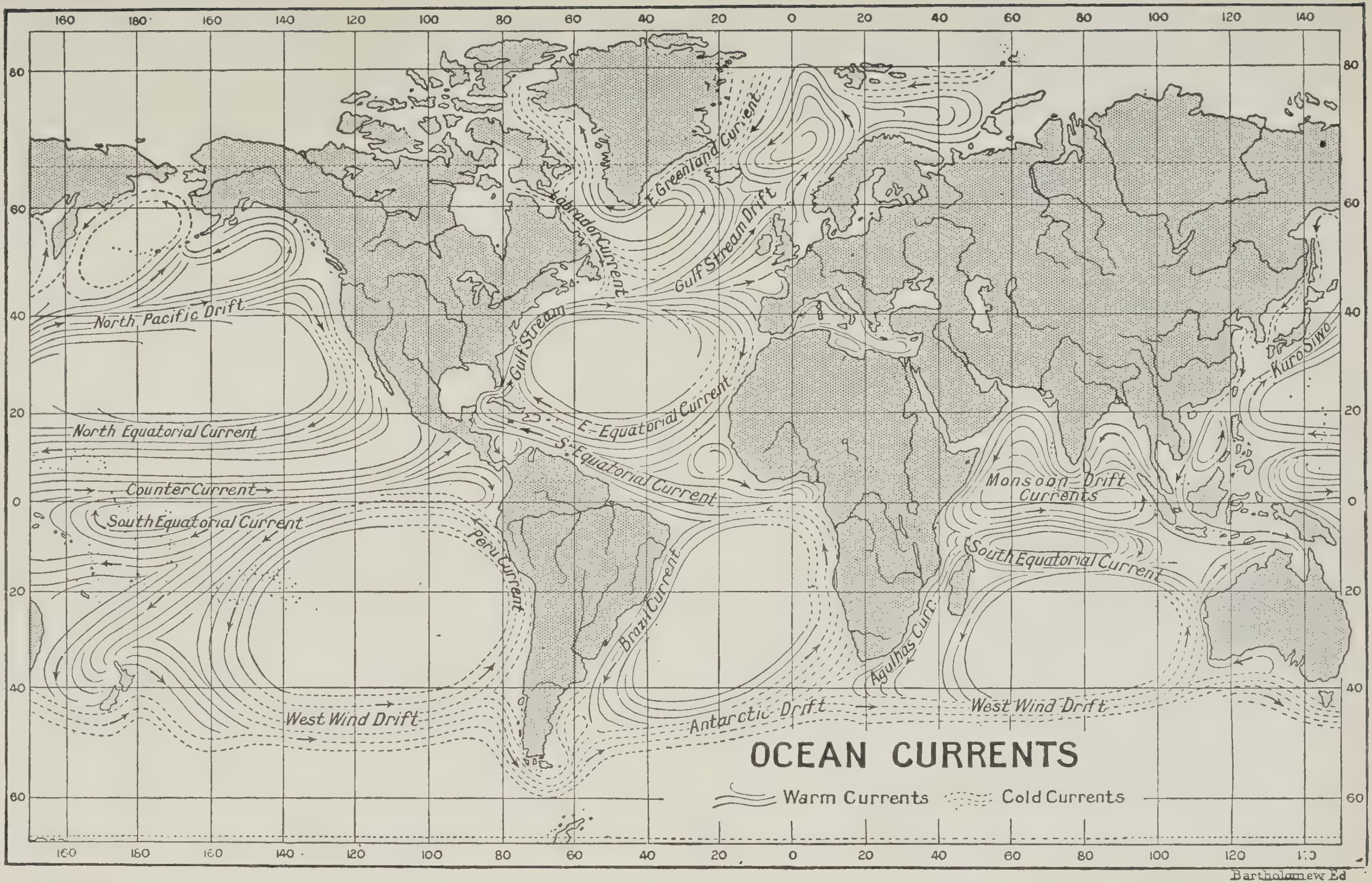

FIG. 30. A MAP OF THE WORLD, SHOWING THE PRINCIPAL OCEAN CURRENTS

From "National Geographical Magazine."

The climatic effects of the Gulf Stream and the Labrador current are most striking. Northern Labrador is treeless and arctic, with only two or three months of foggy and chill summer in the year, while the corresponding coast of Europe includes the comparatively mild regions of Scotland and southern Norway. Harbours are open all the year as far north as Hammerfest, well within the Arctic Circle, while the harbour of Quebec, far south of London, is closed for five months. The same relation seems to have held during the Ice Age, for the European ice sheet reached Lat. 52° only, leaving the southern edge of England uncovered, while the Labrador sheet in America reached Cincinnati in Lat. 38°.

On the Pacific coast the Japan current produces much the same effect as the Gulf Stream, giving a mild climate even in southern Alaska. Prince Rupert in Lat. 54° is never blocked by ice, and the summer isotherms of northern Alberta and British Columbia bend away to the north. The contrasts between the climates of the Pacific and Atlantic coasts of Canada are almost as striking as those on the two sides of the Atlantic.

In the southern hemisphere the cold Humboldt current brings a temperate climate along the western coast of South America to within three or four degrees of the equator; but in general, ocean currents are of less importance than in the north.

TIDES. Even on great lakes, like Superior, tides are insignificant, but on many sea coasts they are prominent geological factors. In a general way tides are caused by the differential attraction of the moon and sun on the water of the ocean and on the earth as a whole. The sea on the side towards the moon is 4000 miles nearer than the centre of the earth and is therefore pulled toward it; while on the opposite side it is 4000 miles farther away than the centre of the earth and so is left behind. Thus two tides are caused by the attraction of the moon, one on the side towards it and the other on the side opposite. The same is true of the sun but on a smaller scale, since the sun is so much farther away. The highest or "spring" tides occur when the moon and sun are either on the same or on opposite sides of the earth, and the lowest or "neap" tides when they are at right angles to one another and pulling at cross purposes.

(*a*)

(*b*)

FIG. 31. TIDE AT WOLFVILLE ON BAY OF FUNDY

(*a*) *In.* (*b*) *Out.*

In the open ocean the tides average from four to six feet, but on many shores where funnel-shaped bays lead inland they are compressed and become much higher, as at Quebec, where they reach fourteen or eighteen feet. On the Bay of Fundy and at Cape Chidley at the north end of Labrador, tides may rise forty or fifty feet or even higher under special circumstances and do a large amount of work.

It might be supposed that the west side of America would be sheltered from the tides, but when the great oceans are stirred by these motions they spread in all directions and are almost as marked in Vancouver Harbour as at Quebec.

Twice a day the tide advances upon the land and then recedes. In narrow bays like Fundy it rushes in as a powerful current and even moves as a low wall of water far up rivers, causing a "bore." This is well seen at Moncton.

These inward and outward motions stir up the mud in shallow waters, making the sea red instead of blue along the Fundy shores, and evidently scour the bottom and transport mud to the deeper water off shore.

Tidal currents between islands and the mainland, as at Seymour Narrows north of Vancouver, may be so powerful that vessels cannot make headway against them and must anchor till they change. It is proposed to use the Fundy tide, rushing between an islet and the shore near Cape Blomidon, as a source of power, the main difficulty being that the current is reversed every six hours. To make use of tidal power means setting to work part of the energy of rotation of the earth.

In Evangeline's country the great tidal meadows are diked, and by admitting the tide at high water and allowing it to deposit its mud before releasing it, the surface has been built up to higher levels in the region of Grand Pré.

There can be no doubt that tidal friction serves as a brake on the rotation of the earth and is very gradually lengthening the day.

The Salts of the Sea. The saltness of the sea is one of its most striking features and is of great interest geologically. As all rivers which flow to the sea carry down various salts in solution, while the water evaporated from the sea is pure, it is evident that the salts must accumulate from age to age. The length of geological time has even been calculated at

about 90,000,000 years by dividing the annual increment of sodium as brought in by rivers into the total amount of sodium contained in the salts of the sea.

If 100 pounds of sea water are evaporated about 3½ pounds of solids remain, nearly 78 per cent. being sodium chloride, 11 per cent. magnesium chloride, giving sea water its bitter taste, and the rest various salts in smaller amounts, including sulphates of magnesium, calcium, and potassium. It seems curious that the commonest substance in spring or river water, calcium carbonate, is present only in very small amounts; but this is accounted for by the work of marine animals and to a less extent plants, which are constantly removing it to build shells, coral, etc.

The salts are very uniformly distributed through the open sea, analyses showing practically the same amounts wherever the samples are collected, even when taken from great depths when sounding, and it is certain that there is a great but slow system of circulation keeping the waters thoroughly mixed, the cold arctic waters sinking and travelling towards the equator, while the warm equatorial waters spread superficially toward the poles. Even under the equator the water at great depths is not more than a degree or two above the freezing point.

This circulation carries down oxygen in solution also, providing for the needs of the deep-sea animals and removing the carbon dioxide formed by their breathing.

While the salts of the sea are constantly accumulating there are means also by which they can be removed. If a bay is cut off by a bar or by a change of level of the bottom in a region of desert climate, the water will be evaporated and a bed of salt deposited. This process may be repeated several times, forming bed after bed of salt separated by shale or impure limestone, as in the salt region of south-western Ontario.

Deposits in Salt Lakes. Similar deposits are formed in inland regions with a dry climate where rivers supply salts in solution to lakes without outlets; but the salts may vary greatly in character according to the soluble materials contained in the soils through which the rivers flow.

In Canada lakes without outlets are found in the drier

parts of Saskatchewan, Alberta, and British Columbia. Some of these lakes, such as the Quill lakes and Old Wives lakes, are extensive and have several streams flowing into them, but are not heavily charged with salts. In western Canada lakes of this kind are usually called alkaline, though most of them contain only neutral salts, such as sodium or magnesium sulphate. A few are actually salt lakes charged with common salt. In central British Columbia there are several small lakes containing special salts, some having practical value, like the deposits of hydromagnesite near Clinton and

FIG. 32. BORAX LAKE AND THE VOLCANO OLLEGUE, BOLIVIA

at Atlin, and the ponds with epsomite and sodium carbonate near the former place.

More famous salt lakes occur in countries having actual deserts. For instance, Great Salt lake in Utah is a saturated solution and is depositing salt, and the Dead Sea of Palestine is of the same kind. Dried-up lakes on the tableland of Bolivia are white with borax, and several other salts are deposited in desert lakes in different parts of the world.

Marine Deposits. Gravel, sand, and mud derived from the attack of waves on the shore or brought in by rivers are deposited in the shallow waters offshore; but "terrigenous" deposits, as these are called, play only a small part in the deposits of deeper seas. Beyond the shelf bordering the

continents, often for a width of 150 or 200 miles, the bottom sinks rapidly to great depths, reached only by the finer muddy products or by volcanic ash or pumice. With these materials there are innumerable microscopic shells of foraminifers, forming a greyish ooze. Below 2000 fathoms there is sufficient carbon dioxide present to dissolve shells formed of lime, and the abyssal deposits below this are formed with extreme slowness. Siliceous shells, small concretions of oxide of manganese, teeth of sharks, and ear-bones of whales, the most resistant parts of their structure, may be dredged from even the deepest seas.

There seems to be a small amount of life existing at even the greatest depths in total darkness and a nearly freezing temperature, the organic matter slowly settling to the bottom, from the death of creatures near the surface, supplying the necessary food.

THE WORK OF SNOW AND ICE

Water in the solid state appears as skeleton crystals in snow and also in the massive form as ice. Snow entangles much air in its descent and thus forms a non-conducting covering for the earth, practically putting an end to epigene work for the time. Snow may also be considered a reservoir of water which is discharged when the thaw comes in spring. Most Canadian rivers have their greatest floods then, and do more work in the time of melting snows than in all the rest of the year. The annual floods of the Thames and Grand rivers illustrate this.

Most rivers and all but the largest lakes freeze over in winter in our climate, sometimes to a thickness of two or three feet. The ice covering a lake expands with a rising temperature like any other solid, and may push boulders outwards along the shore, sometimes forming a kind of wall or rampart in this way, as at Lake Simcoe.

Rocks frozen into the ice along shore may be rafted off when the ice breaks up, and afterwards may be left stranded at some other point. The large blocks often piled on exposed points in the Thousand islands, River St. Lawrence, have been transported in this way. Ground ice formed at the

bottom of rapid rivers, as in the Hudson Bay region, may also float off boulders to be dropped when the ice melts with the advance of spring.

Glaciers. The most important work of ice is done, however, in places where snow lies permanently, as on high mountains or in the Arctic regions. In all parts of the world, even under the equator, there is an altitude above which the snow does not melt in summer. This level is called the snowline, and it is fixed partly by the temperature and partly by the amount of snowfall. In southern Canada perpetual snow is found in

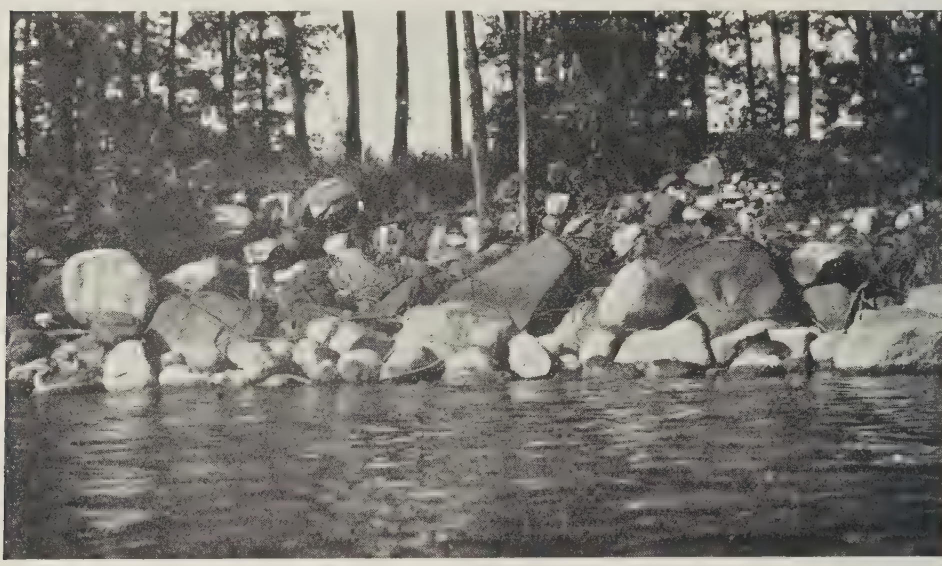

FIG. 33. ICE RAMPART, LAKE SIMCOE, ONTARIO

the eastern Rocky mountains at about 9000 feet and in the western Selkirks at 7500 feet, the latter facing the Pacific and having a snowfall often reaching from thirty to fifty feet per annum. Farther north the snowline lowers, while toward the equator it rises and sometimes reaches 16,000 feet or more in the tropics.

From steep slopes the snow may slide down bodily into the valleys, especially toward spring, sweeping everything movable with it and mowing down forest trees in its path. The Canadian Pacific Railway has built many miles of snowsheds to protect its line from such snowslides or avalanches. In most cases, however, the slopes above snowline are not steep enough for slides, and the snow heaps up year after year until hundreds

of feet may accumulate. Permanent snow receives the name of *névé* from the Alps where glaciers were first studied.

The pressure of overlying snow and a small amount of melting and freezing gradually turn the lower layers into ice which generally has a distinct stratification. The ice thus

Photo. by A. O. Wheeler

FIG. 34. GLACIER ON MOUNT BALFOUR, ROCKY MOUNTAINS, SHOWING NÉVÉ FIELDS, ICE FALLS, AND MEDIAL MORAINES

formed moves down below the snowline into the valley and is called a glacier, which ends where the rising temperature at lower levels thaws the ice as fast as it descends. As the whole ice field tends to pull away from the sides of the valley, an irregular gap is left round the upper edge, called a "bergschrund."

The motion of a solid substance like ice merely under the

pressure of its own weight is not easily explained, though the fact of "regelation" aids in its movements. Water expands when freezing, unlike almost all other substances, so that pressure lowers the freezing point, and where the pressure is greatest the ice may change to water, which slips to a point of less pressure and becomes solid again. Glaciers are made up of separate grains or small individual masses of ice which can move among themselves under pressure and become re-cemented when the pressure slackens; and glaciers can

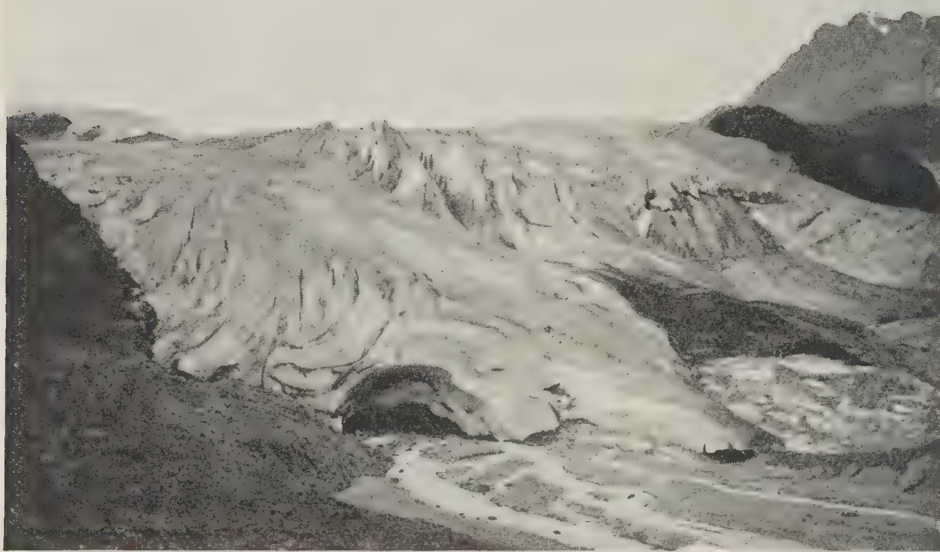

Photo. by Byron Harmone

FIG. 35. ICE CAVE AND RIVER AT END OF YOHO GLACIER, BRITISH COLUMBIA

adjust themselves to changes of grade by breaking across, also, forming *crevasses*, great fissures often extending to the bottom. When the obstruction is past, regelation comes into play and the ice becomes solid once more. On steep irregular descents the glacier is often broken up into ice pinnacles called *seracs*, which disappear, however, lower down.

The flow of glaciers is like that of a plastic body, such as pitch, and their motions are very slow, usually not more than one foot a day and never more than sixty feet. The centre of a glacier moves faster than the edges owing to friction on the floor of the valley.

As the ice is solid, any rocks or debris slipping down from the cliffs alongside are carried down on its surface as "lateral

Photo. by Melson

FIG. 36. MEDIAL MORAINE, ALASKAN BOUNDARY

moraines." When glaciers meet, the two adjoining lateral moraines join to make a "medial moraine"; and where the

FIG. 37. TERMINAL MORAINE, MAIN GLACIER, MOUNT ROBSON, B.C.

ice finally melts, all the transported material is dumped in a crescent-shaped ridge called a "terminal moraine."

Work is also done beneath the ice, where all loose bits of rock are frozen in and used as chisels and gouges, while the finer stuff serves as sand-paper and polishing powder. The mass of rocks and finely ground "rock flour" dragged along in the lower part of the ice is left behind as *boulder clay* or *till* when the ice melts. Many of the stones in the clay have their corners blunted and have smooth faces ground upon them, which may be scratched by hard projecting points as they are forced along. Such stones are called *soled boulders* or *striated stones,* and are very characteristic of ice action, since no other agency produces such effects. Scattered stones left after the glacier melts are called *erratics.*

FIG. 38. BOULDER CLAY WITH STRIATED STONES, TORONTO, ONTARIO

The rock surface beneath the ice also may be polished and striated, and hills of harder rock may have rounded forms on the side from which the ice advanced, and are called *roches moutonnées* (sheep rocks). In the lee of such hills of rock boulder clay or loose debris may be protected, giving the arrangement called *crag and tail.*

FIG. 39. STRIATED STONE FROM BOULDER CLAY AT TORONTO, ONT.

Since glaciers move so slowly as compared with water, to drain a given area they must have an enormously greater channel. Accordingly the former V-shaped river channels are enlarged and carved into wide and deep

U-shaped valleys when ice occupies a region. Finally, small mountain glaciers hollow for themselves armchair-like nests called *cirques.* All of the features mentioned above are well seen in the Rocky mountains below the present level of ice action, and all but the U-shaped valleys and cirques are typically shown in eastern Canada as a result of glaciation in the Ice Age. Where a U-shaped valley has sunk below sea level it forms a long narrow inlet called a *fiord.* The ragged outlines of the coast of British Columbia, Labrador, and other regions once glaciated illustrate this feature excellently.

FIG. 40. ROCHE MOUTONNÉE AND STRIATED SURFACE, COPPER CLIFF, ONTARIO

ICEBERGS. Where glaciers reach the sea, masses of ice break off and float away as icebergs. These may be of all shapes and sizes, some in the Antarctic regions even reaching several square miles in dimensions. Any morainic material upon the ice is carried along by the icebergs. Thousands of bergs "calved" from the Greenland glaciers are carried in long processions southwards by the Labrador Current, at the rate of about a mile an hour. These often reach the Banks of Newfoundland and get aground there, where the warmer air and water rapidly melt them, dropping their load of clay and stones upon the banks, which are being built up of materials freighted from Greenland, a thousand miles away.

A few of the bergs go still farther south and get into the path of the transatlantic steamers before finally melting.

DRIFT DEPOSITS

The whole series of deposits formed by ice and by the glacio-natant waters—waters coming from the marginal melting of the ice sheets—is called *drift*. The greater part of Canada is covered by drift, those areas which were not worked over

FIG. 41. CIRQUE NEAR MOUNT TETRAGONA, LABRADOR

by ice being called *driftless*. The largest area of the kind in Canada is in Yukon territory; but the higher parts of British Columbia escaped ice action, and a few thousand square miles in the far north-east of Labrador, on the Torngat table-land, are also driftless. In southern Canada only a small area above 2500 feet in the Shickshock mountains of Gaspé shows no signs of ice action.

In most parts of Ontario and Quebec the present surface of the country still preserves the characteristic landscapes left by the great ice sheets which vanished thousands of years ago; and, as mentioned earlier, the arrangement of lakes and rivers is closely related to the work of the ice.

THE ATMOSPHERE

Air and water are close partners, and several results of atmospheric work have been mentioned, such as weathering and the causing of waves and currents.

The air consists essentially of two gases, nitrogen and oxygen, with a variable amount of water vapour. The specific gravity of dry air is about $14\frac{1}{2}$ as compared with hydrogen, and that of the gaseous form of water is 9, so that water vapour is the lighter of the two. The weight of the atmosphere at sea level is about 14 pounds per square inch, or equivalent to a column of mercury 30 inches high. At 18,000 feet above the sea its weight is only half as much. The upper limit of the air is vague, since the gases grow rarer until, at about 100 miles, they are no longer dense enough to cause meteors to glow by friction.

The pressure of the air is constantly changing, partly by variations of temperature and partly by the evaporation of water or its precipitation as rain or snow. Expansion of the air by heat causes it to rise, while colder air comes in to take its place, producing winds.

The most uniform of winds are the *trades* of the tropics, caused by the ascent of warm, moist air under the effect of a vertical sun. As the air sucked in from north and south comes from regions of less motion of rotation than at the equator, where the surface travels 1000 miles an hour, these winds appear to lag and move in diagonal directions, becoming respectively north-east and south-east trades. As the air brought in by the trades comes from cooler latitudes and is warmed up as it approaches the equator, the trade winds themselves are dry, though the zone of calms, the doldrums, where they almost meet, is excessively rainy.

Other important but more local winds called *monsoons* are seasonal, blowing inwards toward heated tropical lands in summer and outwards from the cooler continent toward the warmer seas in winter. Many parts of India are dependent on the rains brought by the monsoons for their agriculture, and a failure of the monsoon means famine.

In temperate regions the great cyclonic storms, such as those which cross Canada from west to east, are of most

importance, though the west or north-west winds, which blow more commonly and are sometimes called the *anti-trades*, have much effect on the winter climate.

One strongly blowing west wind, crossing the mountains of British Columbia, and becoming warm and dry by compression as it descends thousands of feet to the foothills and prairies of Alberta, is famous as the *chinook*, which licks off

FIG. 42. SAND DUNE NEAR WELLINGTON, ONTARIO

the winter's snow and renders possible the cattle and horse ranches of the region.

Work of the Wind. On dry land the commonest work of wind is the lifting and transport of dust, familiar everywhere. In desert climates this becomes of great importance, and immense quantities of fine rock particles travel in the direction of the prevalent winds. In moister regions where there are streams and pools and vegetation this dust is halted and builds up a soft, unstratified rock called *loess*, the best example being found in China, where dust from the desert of Gobi to the east has formed in places hundreds of feet of loess.

Wind has one advantage over water as a transporting agent, since it can carry its load up-hill and remove it completely even from an enclosed basin, whereas water can only work downwards and can do no work below its base level. The winds can lift and carry bodily small dust particles, but grains of sand are too heavy to be carried in this way by ordinary winds, so that the grains are only lifted a few inches and then dropped. By constant repetition great masses of sand are thus moved, forming *dunes.*

FIG. 43. BAD LANDS SHOWING WIND SCOUR, RED DEER RIVER, ALBERTA

Dunes are shifting hills, advancing in the direction of prevalent dry winds. When wet the wind has no power to lift sand. The most perfect dunes are naturally found in deserts, *e.g.* in Nubia or Peru, and take the form of a crescent or horse's hoof, with its outer curve facing the prevalent wind. On that side a low stream of sand grains may be seen dancing upwards to the crest and then dropping in the eddy which forms a steeper slope on the inner face. The surface of the sand is rippled. Such regularly formed desert dunes are sometimes called *barchans.*

Sand dunes are to be seen near Wellington in Prince Edward county, Ontario, on the north shore of Lake Erie, and at

many other places. They are sometimes serious invaders, covering fields and orchards and even houses. In the Old World they have been conquered by planting certain kinds of grasses, followed by pine trees.

Winds do important work also in scouring and wearing down by a sort of sandblast action all rocks exposed to driving particles in desert regions. Egyptian monuments facing the desert often have their inscriptions destroyed in this way; but good examples are not found in Canada.

One effect of the work of dry, powerful winds is the drifting of the lighter soils from the fields in southern Alberta. This soil-drift, as it is called, is a serious menace to the wheat-fields near Lethbridge, Alberta. The thin prairie sod protects the sandy soil beneath, but when broken and not covered by a crop the whole surface may be blown away by a strong west wind, so that the air for miles to the east is thick with dust particles.

LIFE AS A GEOLOGICAL FACTOR

Life is closely bound up with water and air and also with sunlight, since all the food of the world originates in the work of plants containing chlorophyll. For at least part of the year water must be in the liquid form if life is to continue, so that a suitable temperature is necessary also. The individual living being is insignificant, but the power of multiplication makes some species of great importance as rock formers. Both plants and animals have a part to play and will be referred to.

Geological Work of Plants. Soils. Plant life exists in some form in almost every part of the world except on wide snowfields and a few of the driest deserts, such as the nitrate region in Chile. The relation of plants to soils is a fundamental one and may be considered first. Most soils consist of a basis of finely divided mineral matter mixed with humus, the product of decaying plant remains, a good soil containing from 5 to 20 per cent. of organic materials. The mineral basis of a soil may be sandy, clayey, etc., and should contain supplies of indispensable chemical elements, especially phosphorus, potash, lime, and sulphur.

The beginning of soil production in a new region, *e.g.* one just freed from a sheet of ice, is generally made by the growth of wind-borne lichens, since the lichen is a very efficient partnership of a fungus with an alga, the latter supplying food and the former attending to outward relations. The death and decay of lichen after lichen prepares the way for wind-borne spores of mosses, and the mossy sponge gives lodgment for ferns and bird-sown, berry-bearing plants, followed by trees with winged seeds. Ultimately a considerable thickness of humus is built up.

The decay of roots affords some mixture of organic with mineral matter in the soil, but the aid of earthworms or burrowing mammals, such as the mole or the western gopher, is necessary for the proper stirring up of the soil ingredients.

Protective Work of Plants. Once a soil is prepared in most temperate climates a covering of grasses and other low-growing plants forms a sod or turf, or else forest spreads, protecting the soil from wind or rain erosion. It is interesting to note that the "bad lands," almost useless because so completely gullied and scoured by rain, are found in regions of low rainfall, since the water supply is not sufficient for a complete mat of grasses, while the well-protected prairie with larger rainfall scarcely suffers at all in this way.

The protective effect of forests is well known. They specially regulate the run-off of rain and the sudden thawing of snow, thus spreading the flow of water more evenly over the year. Many mill streams used in Ontario in earlier, better wooded days now dry up in summer, and in several countries forest land is preserved at the headwaters of important rivers, to regulate their flow. The forest lands of the foothills and mountains in Alberta have been reserved by the government largely to protect the headwaters of the rivers which flow eastwards into the plains.

Rock Formation by Plants. A number of plants secrete hard parts which accumulate to form beds of rock. The delicate siliceous shells of diatoms are good examples of this, forming beds of *diatom earth* on the bottom of lakes, as in Muskoka. This material is of some value as an abrasive.

The formation of travertine and of bog iron ore beds is largely due to mosses and other plants removing carbon

dioxide from the solutions of lime or iron compounds, thus depositing them about themselves.

In the sea, nullipore seaweeds (*Lithothamnion,* etc.) secrete carbonate of lime and may form great masses of limestone, usually in partnership with marine animals; while chara and other plants help in depositing marl in fresh waters.

The mangrove tree, growing densely along protected shores in the tropics and sending down aerial roots in all directions, fixes the mud brought by the tides and slowly extends a slimy, foul-smelling margin of land into the shallow sea.

Fossil Fuels. Much the most important geological work of plants from the economic side is the storing of their own tissues in bogs or shallow water as peat, which may later be transformed into coal. The growth of peat may be studied in many places in all the provinces of Canada, the Indian term, muskeg, being generally used instead of the Old World name, bog.

Certain mosses, especially sphagnum, are active in this work, but many other swamp plants take a part in it, and the leaves and branches or trunks of trees near by may also be enclosed in peat. While plant tissues decay completely on dry land, under water in the presence of tannin formed in the bog the decay takes a different course and is much less complete. The main change going on is the escape of two gases, carbon dioxide, and methane or marsh gas, a compound of carbon and hydrogen, diminishing the amount of oxygen and hydrogen present. Thus peat changes from a pale brown on top of the bog to black muck at the bottom, the latter being richer in carbon and poorer in oxygen and hydrogen compounds.

But for the fact that peat clings tenaciously to the last 25 or 30 per cent. of water, so that it cannot be dried beyond that stage by ordinary means, it would provide a most excellent fuel.

Materials originally like peat but buried for long periods of time advance farther in the loss of gases mentioned, and form *lignite,* which generally retains from 15 to 30 per cent. of water. Sub-bituminous coal comes next, containing less water, and finally true bituminous coal, with very little water and 55 or more per cent. of fixed carbon, the rest consisting of

hydrocarbons which burn with a yellow smoky flame. Where mountain-building stresses cause folding of the beds of bituminous coal, most of the remaining hydrocarbons pass off and anthracite or hard coal remains, containing 80 per cent. or more of fixed carbon and so little volatile matter that it burns with a blue smokeless flame. Anthracite is the rarest variety of coal and is nowhere commonly used except in the eastern United States and Canada, and the known supply may not last for more than a generation longer.

Practically all types of coal, from low-grade lignite to semi-anthracite, occur in Alberta and British Columbia, where all stages of change are found to be related to the amount of disturbance and folding of the enclosing rocks, lignite occurring in flat, undisturbed beds and the higher grades where mountain-building forces have been at work.

Geological Work of Animals. The geological work done by animals consists chiefly in bequeathing their hard parts for the formation of limestones, a work in which most of the types of animals except the highest, the vertebrates, are of some consequence. Two very low types, the protozoöns and the polyps, are particularly efficient.

Foraminifers. Many of the unicellular animals form shells of lime, through which there are many little pores or openings for pseudopodia, thus justifying the name foraminifer; and most of them cluster in small colonies, like *Globigerina*. Their minute shells accumulate in vast numbers on certain sea bottoms as a greyish ooze, which ultimately may be consolidated to limestone, particularly the soft variety called chalk. The white cliffs of Albion are of chalk which consists mainly of foraminiferal shells.

Along with the lime-secreting protozoa there are, in smaller numbers, some which build their shells of silica. These with the siliceous spicules of slightly higher animals, the sponges, may form siliceous beds. Usually, the silica is aggregated into nodules or concretions, as flint in chalk, while in older limestones the result is chert, which differs little from flint. Most foraminifera are of microscopic size; one group, the nummulites, however, grew to be quite large, their flat shells reaching the size and shape of a coin, which suggested the name "coin animal." Their shells were deposited on a tremendous

scale in the Mediterranean region during Eocene times, forming widespread nummulitic limestones, some of which have been built into the famous pyramids near Cairo.

Corals. Among the most impressive rock builders are the polyps which secrete coral, but their work, except on a minor scale, is confined to warm climates (68° F. as a minimum) and clear seas, within a depth of about 150 feet. Under these conditions corals of numerous species, aided by some other animals, as well as nullipore algæ, build massive reefs either along shore, as *fringing reefs*, or separated from the shore by a channel, when they are called *barrier reefs*. When a reef surrounds a lagoon, either with or without islands, it is called an *atoll*.

The corals do not build up a solid mass of rock, but the waves break off and grind up projecting corals, filling in the spaces and cementing the whole solidly together. One or more openings permit the movement of tides and currents through barrier reefs and atolls, and the coming-in of a river with fresh and muddy water always causes a gap in the reef. Good harbours, like that of Mombasa in East Africa, may be formed in this way.

A theory proposed by Darwin and supported by Dana and other geologists accounts for atolls as being built up stage by stage round islands on a sinking sea bottom, a fringing reef changing to a barrier reef separated by a channel from the island, and the island itself finally disappearing, leaving only the ring of upgrowing coral reef with its wave-built islets covered with palm trees.

This theory is certainly correct for the island of Funafuti, north of Fiji, where borings show reef materials to a depth of 1114 feet, and is probably true of many other atolls. In other cases, however, there is no evidence of the supposed sinking of the sea bottom, and another explanation must be looked for. The greatest coral reef in the world extends as a wide barrier for 1100 miles along the north-east coast of Australia, affording a well-protected channel for shipping for the whole distance.

Shell Fish. The different orders of shell fish, aided by sea urchins, starfish, etc., probably do even more work in removing the lime from sea water to form their shells than the polyps

do in the building of coral, but their work is scattered on all sea shores, even in the Arctic zone, and is nowhere heaped up monumentally like a coral reef. Many of our Palæozoic limestones are made up almost wholly of their shells, and they have been great rock formers from the Cambrian to the present. Marl, deposited mainly by shell fish in our lakes, is of importance in the making of Portland cement.

Vertebrates. There are a few operations carried on by vertebrates which have a geological bearing, although the

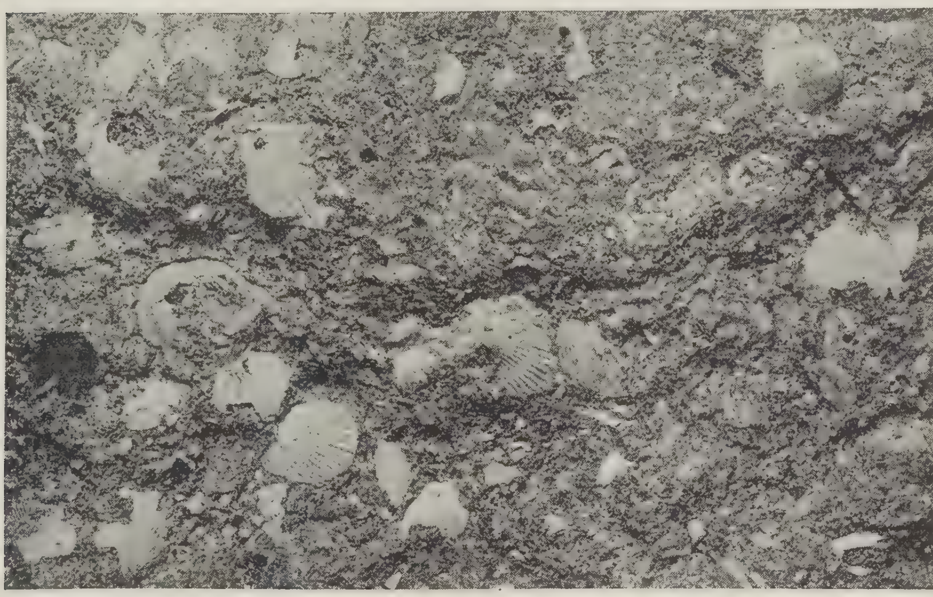

FIG. 44. TERTIARY LIMESTONE WITH SHELLS

results are trifling as compared with those of the foraminifers, corals, and shell fish.

Seabirds, for instance, form thick deposits of guano on islands off desert coasts, as near Chile and Peru. Though these are removed by man as a most useful manure, the clouds of seabirds gradually replenish the supply.

Among mammals the beaver and man perform engineering work influencing geological processes. The beaver's dams form lakes in which the forest perishes, peat and silt are deposited and ultimately a "beaver meadow" is created.

Man is far the most active geological agent among mammals, as a farmer clearing and cultivating the land, as a builder of cities whose crumbling bricks may form the only hills in a

flat plain like that of Mesopotamia, and as an engineer building dams and embankments, excavating canals, mining the sulphides hidden in the earth and roasting them, thus destroying vegetation and exposing bare hills and plains to rain erosion. The mining and burning of coal, restoring to the air carbon dioxide removed millions of years ago, may slowly modify the climates of the world. The activities of man in shaping the earth to his needs or wishes go beyond the usual province of geology, however.

CONFLICT OF FORCES IN THE WORLD

From the account of the epigene forces just given it is evident that their general tendency is destructive, the tearing or wearing down of all projecting parts of the earth, mountains, plains, continents, and islands, and the deposit of the materials as sediments beneath the sea. In time even the lowlands would disappear by solution, and where land once was there would remain only shoals in a universal sea. The hydrosphere, now covering nearly three-fourths of the earth's surface, would then cover the whole and become complete.

This nihilistic work of water and its auxiliaries has been in progress since the earliest known times. Even in the very earliest ages (Grenville and Keewatin) waves and rivers worked effectively, since water-formed sediments were laid down on a large scale.

Though the work of destruction has been unintermitting it has never succeeded in conquering the lands and covering them with the sea. After every lowering they have always risen again, so that in the main the continental masses seem to be permanent.

The conservative factors in the world have been the hypogene forces which have constantly been engaged in uplifting lands and depressing sea bottoms, restoring the inequalities which the epigene forces strive to abolish. The earthquake and the volcano, the two most dreaded manifestations of these subterranean adjustments of the earth's crust, may destroy a city, a human anthill, from time to time, but the

full result of the hypogene forces is eminently constructive and restorative.

The failure of either side to win a final victory in the great war of forces has made the earth the wonderful and beautiful and habitable globe which we know; and the contest, so vital to the existence of all living beings, is going on all around us and should arouse our keenest interest.

GEOLOGICAL TIME

In summing up the effects of many of the forces which have been referred to, the element of time becomes a factor of great importance, since great results may come from the slow accumulation of individually trifling contributions, like particles of dust blown by the wind or the invisible shells of foraminifers. Geologists then are greatly interested in the length of time available in accounting for the changes which have gone on in the world.

There are various ways of computing the length of past time, some purely geological, others astronomic or physical.

As an example of geological methods one may take the number of years required to provide the amount of salt in the sea, supposing that it has all been brought in by rivers with their present annual contribution of salt. This works out to about 90,000,000 of years.

Attempts have been made to sum up the maximum thickness of sediments deposited in different ages of the world, assuming a definite rate of formation for each variety of sediment, and results have been reached ranging from 70,000,000 years to more than twice that length of time.

Physical methods of estimating the permissible length of geological time have been founded on the rate of cooling of the earth, following the nebular theory; and on the slowing down of the earth's motion by tidal friction caused by the moon. These and other methods were believed a few years ago to limit geological time to not more than 10,000,000 or 20,000,000 years, a quite inadequate supply for the needs of geology.

However, the comparatively recent discovery of radio-

active substances in the rocks has completely altered the situation so far as estimates depending on the cooling of the earth are concerned. From the relations of radioactivity certain physicists suggest that rocks from the Pre-cambrian of Quebec are from 222,000,000 to 715,000,000 years old; and others even extend geological time to 1,310,000,000 years as regards rocks found in the United States and 1,640,000,000 for Ceylon. The estimates drawn from radioactivity have so enlarged the time possibilities of the world's past history that there is ample room for all the operations geologists find necessary in building and transforming the rocks of which the crust is composed.

It is worthy of note that in Canadian geology, which includes the most complete series of ancient rocks known, geological forces like those of the present were at work in the earliest ages. Rain and rivers and large bodies of standing water are implied by the sediments; volcanoes poured out lava streams or showered ashes as in later times; and limestones and carbon even suggest life.

These first of known rocks are far removed from the beginning of the world.

CHAPTER IV

STRUCTURAL GEOLOGY

In the discussion of the dynamics of the world it has been shown that various forces are at work modifying and shaping it in different ways. The structures resulting, that is, the architecture of the world, may now be considered.

FIG. 45. STRATIFICATION OF LORRAINE SHALE AND LIMESTONE, HUMBER RIVER, TORONTO

Most of the land surface consists of sedimentary rocks laid down by water in beds or strata, and it is natural to begin with the most widely spread structures, those of stratified rocks. Afterwards the structures of eruptive or igneous rocks will be considered, and finally those of schistose rocks which may include modified examples of either of the two other types.

STRATA

Water and, to a less extent, wind lay down materials bed by bed, each bed, or stratum, being the result of a more or

less continuous process. Some break or change in the conditions causes a parting of one stratum from another. The thickness of a stratum may vary from an inch or two or even less in fine materials to several feet in coarse deposits such as conglomerate. There may be less marked divisions within a stratum giving rise to lamination.

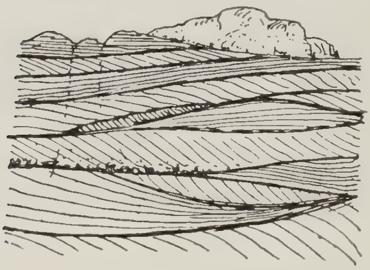

FIG. 46. CROSS BEDDING IN SANDSTONE, DUE TO WAVES AND CURRENTS, THOUSAND ISLANDS, ONTARIO

Where the materials have been dumped intermittently by wave or current action over the edge of a bar there may be *cross bedding* or *current bedding*, with subordinate structures diagonal to the main stratification. This is often seen in sandstones and conglomerates. All strata thin out and end somewhere,

FIG. 47. TIDE RIPPLES, SOURIS, PRINCE EDWARD ISLAND

but their area varies greatly. Where the sediments come from a central point, like the mouth of a river, the strata tend to have an imperfect lenticular form. The surface of a stratum may show ripple marks due to wind or gentle waves or tides, and there may also be rain prints and mud cracks, the latter due to shrinkage on drying. Rarely there may be tracks or footprints of animals. All of these markings

have their bearing on the history of the beds, since they are contemporary records of events.

JOINTS

In almost all cases strata are broken asunder by joints or partings about at right angles to the stratification, and commonly there are two sets of joints cutting one another nearly at right angles. In quarrying the dimensions of the blocks which can be obtained are determined by the thickness

FIG. 48. JOINTS IN LIMESTONE, NAPANEE, ONTARIO

of the stratum and the spacing of the joints. Frequently the direction of the jointage is uniform for long distances, implying a common cause.

Joints may not become apparent in a rock till it is quarried, but in limestones exposed to the weather they may be opened up by solution, forming fissures several inches wide. It is important for the quarryman and the miner to understand the jointage of the stone he is working in, so as to economise labour and explosives and to obtain well-shaped blocks.

The cause of joints is not very well understood, but it is generally looked for in the sudden adjustment of rocks under strain, often accompanied or caused by an earthquake shock. A torsional or twisting strain may be relieved by two sets

of fractures roughtly at right angles to one another, which would account for a common arrangement of joints, and very probably took place in many cases.

CONCRETIONS

Various chemical changes may go on in a rock long after it has become a part of a series of beds, through the action of seeping waters, causing concretions of different materials. The commonest concretions are those of lime in clay or shale, rounded or flattened forms of limestone sharply bounded and remaining after the enclosing rock has crumbled away. When broken there may be a fossil as a nucleus, such as a fern leaf in coal-measure shales or a small fish or shell as in the marine clays at Ottawa.

FIG. 49. CONCRETIONS OF CARBONATE OF LIME FROM PLEISTOCENE CLAY, TORONTO, ONTARIO

The "kettles" of Kettle Point on Lake Huron are large spherical concretions of radiating calcite crystals, which have bent the shale beds apart in their growth, while most lime concretions do not interfere with the bedding.

Concretions of impure siderite (clay ironstone) are of the same kind, and in the coal measures of some countries have been used as iron ores under the names of sphærosiderite or pisolitic ores.

Marcasite (a sulphide of iron) is common as concretions in shales or slate and often occurs in coal.

Flint or chert nodules are really concretions of silica in chalk or limestone.

In sandstones the concretions show little difference chemically from the rest of the rock except for rudely spherical arrangements of limonite. Some of them in the Potsdam sandstone of eastern Ontario are cylindrical, several feet in length, cutting across a number of strata, and even ten feet

in width. They separate easily from the rock like tree trunks, for which they have been taken. The cause of these forms is uncertain and it may be that they should not be included with ordinary concretions.

The evidence that in some cases strata have been pushed aside in the growth of concretions shows that powerful forces have been at work in their formation, chiefly perhaps the molecular forces that build up crystals.

ATTITUDE OF STRATIFIED ROCKS

Most sediments have been laid down on a flat or only gently inclined sea bottom, but in many regions the stratified rocks are no longer in their original position, but are found more or less tilted. The amount of tilt as measured from the horizontal is called the *dip*, which may be expressed in degrees from 0° to 90°. The direction of the dip, *i.e.* of the greatest inclination, should be noted also; and a direction at right angles to it is called the *strike*, corresponding generally to the line of outcrop. At 0° dip the strike is indeterminable, and at 90° the strike is the most salient feature. The dip is not reckoned beyond 90°, though the beds may really have revolved through more than a right angle and may actually be overturned. Instruments called *clinometers* are used to determine dips.

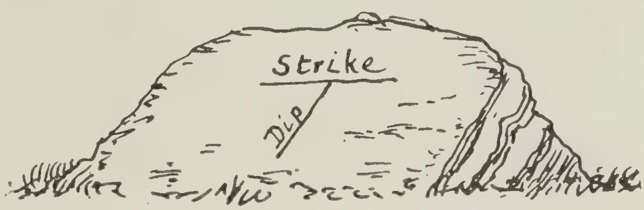

FIG. 50. DIAGRAM SHOWING STRIKE AND DIP

The importance of dip in mining operations is evident. If a coal seam dips uniformly at 20° westwards, one can reckon the depth to which a shaft would have to be sunk in order to reach the coal at a point one mile, for instance, west of the outcrop. However, it should be noted that the dip commonly changes from point to point and cannot be assumed to be uniform for long distances.

FOLDS. In most cases the beds are found to be bent, instead of being tipped as a block on a gigantic scale; and if the curves are followed out one recognises a wavelike arrangement, with

a crest or saddle, which is called an *anticline*; and a trough, called a *syncline*. Occasionally in mountains one can actually see the beds folded into anticlines and synclines, but more often only a part of the fold is visible. Anticlinal ridges and synclinal troughs do not run indefinitely in either direction, but tend to diminish and at length disappear when followed out. Most anticlines are elongated domes and most synclines elongated basins. The amount of bending may be slight, giving open folds, or extreme, when the sides may be forced together, causing a closed fold.

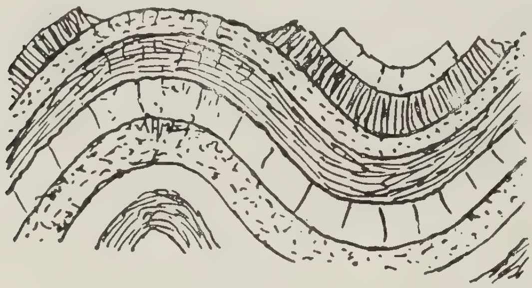

FIG. 51. OPEN SYMMETRICAL FOLD SHOWING AN ANTICLINE OR UPWARD BEND AND A SYNCLINE OR DOWNWARD BEND

Folds may be symmetrical, when a vertical plane would divide the anticline or syncline into similar halves, but usually they are unsymmetrical, and not infrequently they are overturned or recumbent. Folds may be "carinate" when a keel-like anticline or syncline passes upwards or downwards into unfolded beds.

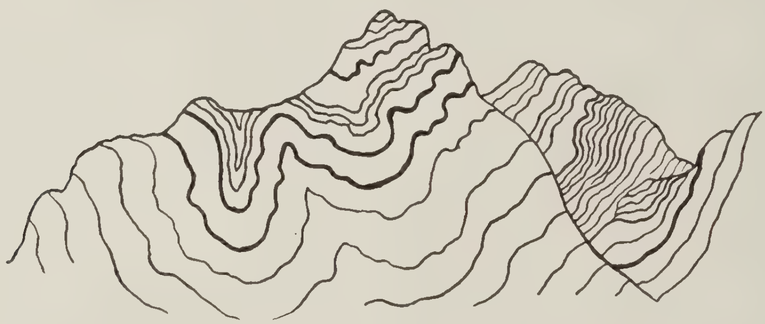

FIG. 52. PART OF FOLDING MOUNTAIN, ATHABASCA GAP, ROCKY MOUNTAINS, SHOWING A COMPLEX SYNCLINE

Folds of various kinds are displayed on a large scale in the Rocky mountains, running parallel to the direction of the range and apparently caused by a powerful thrust from the Pacific. The folded beds may be 20,000 feet or more in thickness.

On the other hand, in parts of the Selkirks and in the older

rocks of the east there may be intricate crumplings of the strata, like wavelets and ripples on ocean waves.

Gentle anticlinal folds or domes are the most favourable localities to search for oil, and synclinal basins are commonly found in coal regions.

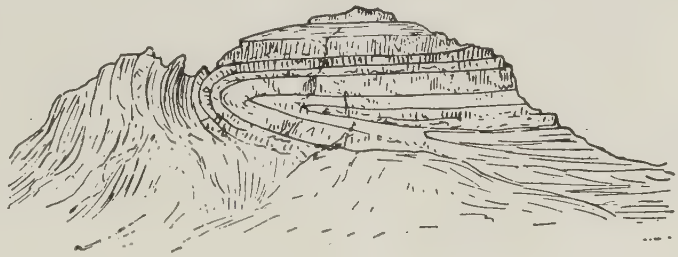

FIG. 53. OVERTURNED FOLD, CLEARWATER RIVER

Where rocks are bent on a very long and broad scale, often with subordinate undulations as well, the terms *geanticline* and *geosyncline* may be used, the latter structure forming the usual beginning for the building of a new mountain range. A long and wide depression of the sea bottom becomes more and more depressed as layers of sediment are piled upon it, until lateral pressure throws the gentle downward curve of the geosyncline into sharper folds of the more common type.

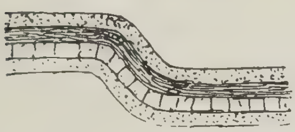

FIG. 54. A MONOCLINE

In addition to the usual folds consisting of an anticline and a syncline there are in some places *monoclinal* folds with the bend in only one direction.

ZONES OF DEFORMATION AND OF FRACTURE

Rocks are mostly hard and resistant solids; some of our building stones, for instance, will stand a tremendous crushing strain, and it is a surprise to find that they can be crumpled into folds like so much cloth or paper. It must not be forgotten, however, that all solids yield under sufficient strain, especially when the process is aided by heat, and act more or less as if they were plastic. In the case of mountain folds one must suppose that there was a sufficient load resting on the beds to force them to yield plastically. We may assume that at a certain depth all rocks may be deformed without rupture, and this region below the surface may be called the zone of plasticity. Above this and reaching to the surface is the zone of fracture.

Rocks differ greatly in strength, and where strong and weak rocks are interbedded there will be an intermediate zone in which some beds, such as shale, yield plastically, and others, such as quartzite, adjust themselves by breaking into blocks. Examples of this kind are found in the Rockies.

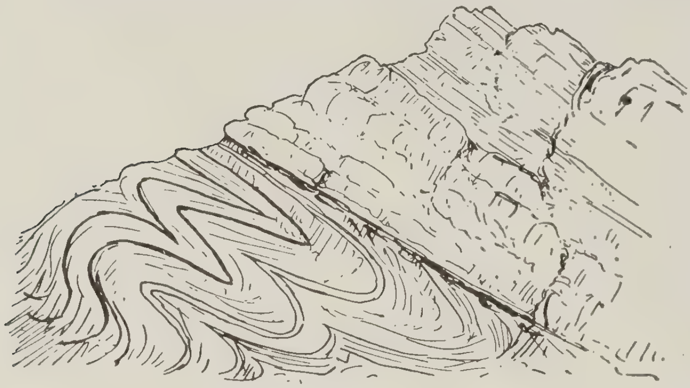

FIG. 55. FOLDING UNDER THRUST FAULT, CLEARWATER RIVER

FAULTS. In the upper parts of the earth's crust we shall expect the rocks to break under sufficient stress, and the blocks thus formed will slip into a new position of rest. Such adjustments take place along certain planes of dislocation and are called *faults*. Usually the shifting is in a more or less vertical direction and

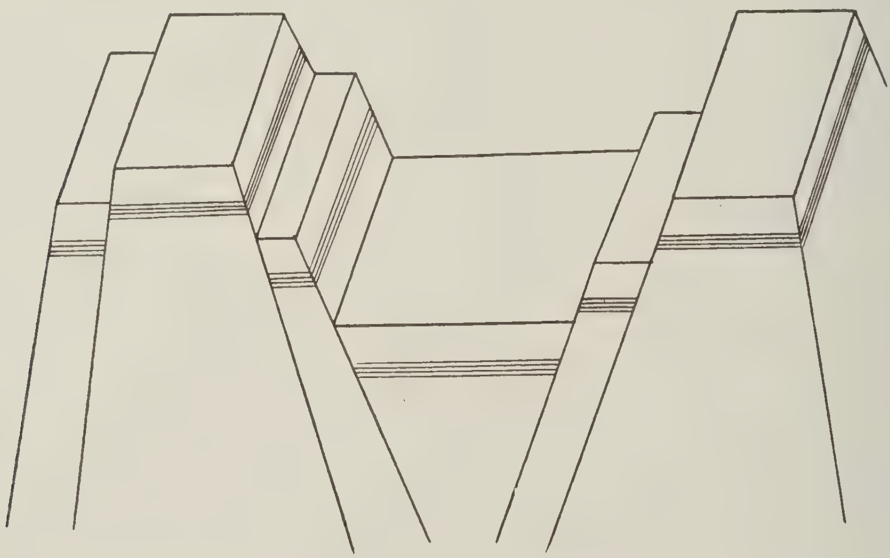

FIG. 56. NORMAL FAULTS, SHOWING A HORST AND A GRABEN

the amount of change of level on one side as compared with the other is called the *throw*. There are, however, faults in every direction, even horizontal, as was proved in the earthquake at San Francisco.

Normal Faults. In most examples of faulting one finds

that there has been expansion of the surface, with a tendency of the blocks to slip down under the action of gravity, the part with the smallest support slipping farthest. This is the natural arrangement and is called *normal faulting*. The surface along which the yielding took place is called the *fault plane*, though it is not always a real plane; and it is often polished or even striated, when it is said to be *slicken-sided*. Usually clay or talc or some other secondary mineral has been formed in a case of slickensides.

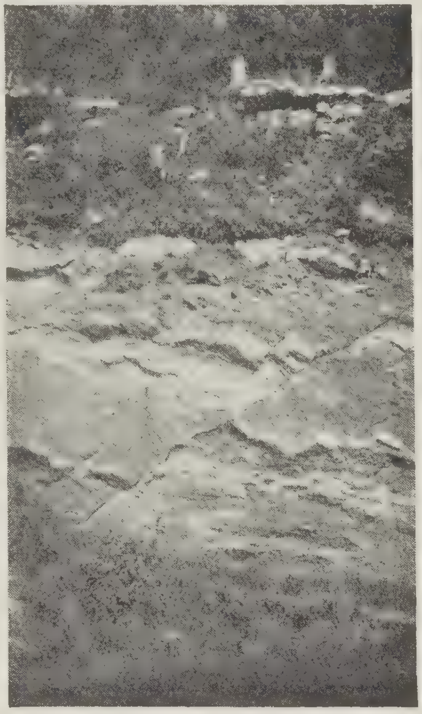

FIG. 57. NORMAL FAULT NEAR NIPIGON, ONTARIO

The throw of faults may be of all dimensions, from a fraction of an inch to thousands of feet, and the amount of throw may diminish in each direction till the fault runs out; or a single fault may divide up into many smaller faults.

Sometimes a solid, broad-based block of rock stands up centrally, while slice after slice slips down on each side, giving rise to a *horst*; and at others the central strip is too poorly supported and drops, making a long *rift* or trough, often called a *graben*. This is sometimes the case where the central part of a gentle anticline yields and sinks, the keystone dropping out of the arch. The basins of Lake Tanganyika and other lakes in Africa are explained in this way, and the basin of the Dead Sea is another example.

Reversed or Thrust Faults. Faults may be caused also by a push which results in an upward movement of the rocks instead of the normal downward slip, and the term *reversed* or *thrust fault* is applied to them. In this case there is compression of the surface instead of expansion, and the type is most frequent and important in mountain regions, such as the Rockies.

In some cases it seems as if long slabs or blocks of the crust

were broken apart longitudinally, and then more or less tilted and thrust one upon another like ice cakes in a spring flood, each riding upon the lower edge of the next one. This is well

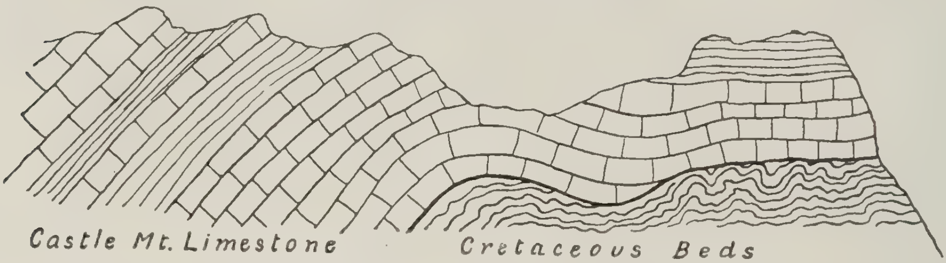

FIG. 58. THRUST FAULT NEAR GHOST RIVER, BOW PASS

Showing Castle Mountain limestone (Cambrian) pushed seven miles over Cretaceous beds. *After McConnell, Geological Survey, Canada.*

shown in the eastern part of the Rockies at Bow Pass, where five blocks may be seen in succession, each with a steep cliff showing the edges of the strata to the north-east and a gentler slope following the dip of the strata toward the south-west. In the case of the outer block the movement has been up a

Photo. by E. S. Moore

FIG. 59. MODERN FAULT CONNECTED WITH AN ALASKAN EARTHQUAKE

somewhat inclined plane for a distance estimated at seven miles. In the highlands of Scotland the Moine thrust fault has driven Pre-cambrian beds ten miles over Palæozoic rocks, and even greater thrusts have been described in Sweden and in the Alps.

There is some reason to think that these thrust faults began as overturned folds, which were torn asunder at the sharply bent crest of the anticline, thus connecting one type of fault with folds. There are examples also of regions which have first been folded and then broken up and rearranged by faulting, giving very complicated structures.

DISCORDANCES

Where sediments are formed continuously, each bed resting regularly and uniformly upon the one below, the strata are said to be *conformable*; but there are many examples known of unconformity or discordance in stratified rocks, where the lower and older beds have been tilted or folded and then planed down by the epigene forces before the later beds were deposited. This gives rise to a *discordance* and indicates an important break in time. The angular difference between the two series of rocks may be of all grades. The beds of the Lower Palæozoic at Gananoque (Thousand Islands) rest flatly upon the almost vertical and greatly distorted Pre-cambrian gneisses and quartzites, the oldest rocks known, and the discordance is one of the greatest imaginable.

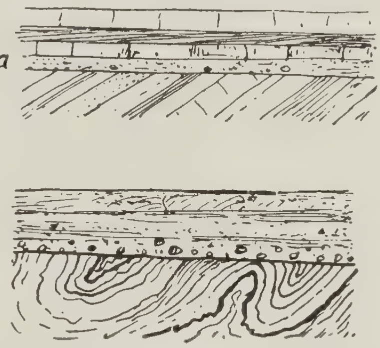

FIG. 60. DISCORDANCES

(*a*) Angular discordance or unconformity in stratified rocks. (*b*) Pronounced discordance between Pre-cambrian and Cambrian rocks, near Gananoque, Ontario.

On the other hand, there may in some cases be no angular discordance separating beds of very different ages, though the older beds may have been eroded into a very uneven surface before the later ones were deposited. This relation may be called *disconformity* to distinguish it from unconformity.

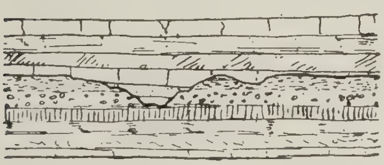

FIG. 61. DISCONFORMITY

The older rocks were eroded but not tilted before the later strata were deposited.

There are cases where the older beds had been thrown into folds and then the surface levelled before the next rocks were formed, so that the later beds sometimes cut

them at an angle and at others, over anticlines and synclines, are parallel with them.

Photo. by W. F. Ferrier

FIG. 62. UNCONFORMITY, UTAH

STRUCTURE OF ERUPTIVE ROCKS

SUPERFICIAL OR VOLCANIC STRUCTURES

The work of volcanoes is open to study on the surface and the resulting structures are well known. Where lava is given

Photo. by Tempest Anderson

FIG. 63. PA-HOE-HOE LAVA, KILAUEA, HAWAII

off from a volcano it forms streams which may spread as wide, flat, thin sheets if the lava is very fluid, or may be short,

thick, and steeply inclined if it is viscid; and all intermediate forms may be found. The thin sheets, if one follows another somewhat regularly, may imitate the arrangement of sedimentary rocks.

Lava sheets or streams usually have peculiar surface features; they may have a fairly smooth but wrinkled or ropy surface, called the *pa-hoe-hoe* surface in Hawaii; or a rough slaggy surface, sometimes extremely rugged, full of projecting points and edges, called *aa* in Hawaii. The internal structure also may be of interest. If a lava stream is somewhat

FIG. 64. AA LAVA, ETNA

fluid in the beginning, steam bubbles may ascend toward the top, where cooling may have advanced too far to let them escape. Thus the upper part of the stream may become vesicular and crowded with small holes. If these holes are very numerous and slender, the light material called pumice may result.

AMYGDALOIDS. Ancient vesicular lava usually has the openings filled with later minerals, such as calcite, agate, and zeolites, and is then called an amygdaloid, the separate inclusions receiving the name amygdules, from the Latin word for an almond. Good examples occur in Keweenawan lavas near Lake Superior.

Pillow or Ellipsoidal Structure. Where lava flows into water its surface is very rapidly cooled and lobe after lobe pushes forward to be quickly arrested, resulting in oval masses piled on one another like sacks of wool or pillows. This structure is found in lavas belonging to our most ancient rocks, the Keewatin.

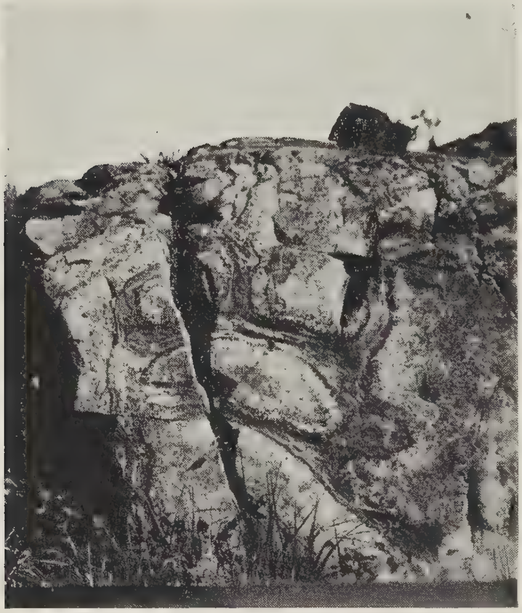

FIG. 65. PILLOW AND AMYGDALOIDAL STRUCTURE, SUDBURY, ONTARIO

Structures caused by Explosive Eruptions. Where explosions take place the lava may be blown into very fine dust, into somewhat coarser particles called *volcanic ash*, larger ones called *lapilli*, and still larger ones, a few inches or even several feet in diameter, called *bombs*. Such bombs may have rotated in the air and have been twisted into a spindle shape, or may have cooled on the surface while gases were still expanding within, the outer crust being fractured, giving the bread-crust structure.

The loose materials may fall on the land or into water, forming tuffs of various kinds, sometimes well stratified.

Since more fragments fall near the crater of a volcano than farther away, the centre grows faster than the edges and a beautiful conical shape may result, as in Fujiyama or Teneriffe; and they may be called *strato-volcanoes* because of this arrangement of the loose materials. In most volcanoes there are both lava streams and fragmental beds, giving a less regular form, and often accidents in the way of explosions may destroy the symmetry. In old volcanoes like Etna eruptions are apt to break out in different places, building parasitic cones here and there on the flanks of the original cone. Such small craters formed wholly of loose materials at a single eruption are often very regularly shaped, and are called cinder cones. Occasionally a lava stream has pushed

out on one side, destroying the symmetry. Cinder cones are well displayed in Mexico (see Fig. 15).

UNDERGROUND STRUCTURES

Dikes. Molten rock originates, so far as known, at great depths, and much the larger part never escapes in volcanoes, but cools below the surface under very different conditions. The commonest form in which eruptives occur is in *dikes*, which are sheets of rock filling fissures, perhaps opened as the magma, or fluid rock, ascended. Dikes are apt to be nearly

FIG. 66. DIABASE DIKES, SAGLEK, LABRADOR

vertical, though they may change their direction and pinch out or split up into smaller dikes. Their thickness may be no more than a fraction of an inch or may reach two hundred yards, and some dikes of diabase extend for fifty miles or more. They are found, often in great numbers, in all the mining regions of northern Ontario, and are in some cases supposed to have brought with them the materials of which the ores were formed. Their walls are very distinct, except in the case of pegmatite dikes, which represent the last part of a granitic magma to remain fluid, and ramify quite irregularly into the adjoining rocks, which were probably still hot when they were injected.

Sheet-like Forms and Laccoliths. Occasionally dikes

can be followed up to a certain level, where they spread out thinly between two beds of sedimentary rocks, forming *sheets* or *sills*, as may be seen on Thunder bay, Lake Superior. In most respects they are like horizontal dikes and need no particular description. The rock must have been very fluid to permit of this; another structure results if the magma is more viscid. Instead of spreading widely the molten material heaps up at a particular level and rises into a cake-like form, called a *laccolith* (stone cistern), lifting up the beds above into a dome. Well-formed laccoliths have a flat floor and dome-shaped upper surface, but they are often very irregular, and

FIG. 67. IDEAL CROSS SECTION OF A LACCOLITH WITH SHEETS AND DIKES
After G. K. Gilbert.

there are intermediate stages between laccoliths and sills, called *laccolithic sills*.

A related structure may take on the shape of a basin, the floor beneath collapsing as the magma ascends from under it, as may be seen in the eruptive sheet which brought with it the Sudbury nickel ores. The sheet in this case was a mile and a half thick and cooled very slowly under 9000 feet of sediments, allowing the magma to split up by the aid of gravity into a lighter rock above (micropegmatite, a kind of granodiorite) and a heavier rock beneath (norite), while the heaviest ingredient of all, the sulphides, settled into the hollows at the bottom.

BATHOLITHS. Laccoliths are known to rest upon a floor of older rock, but a somewhat similar, though usually larger

structure, called a *batholith* (rock of the depths), seems to reach down indefinitely, its foundations never having been seen, perhaps because erosion has not gone deep enough to disclose them or perhaps because the materials join on to a layer of similar plastic rock below. Batholiths dome up the

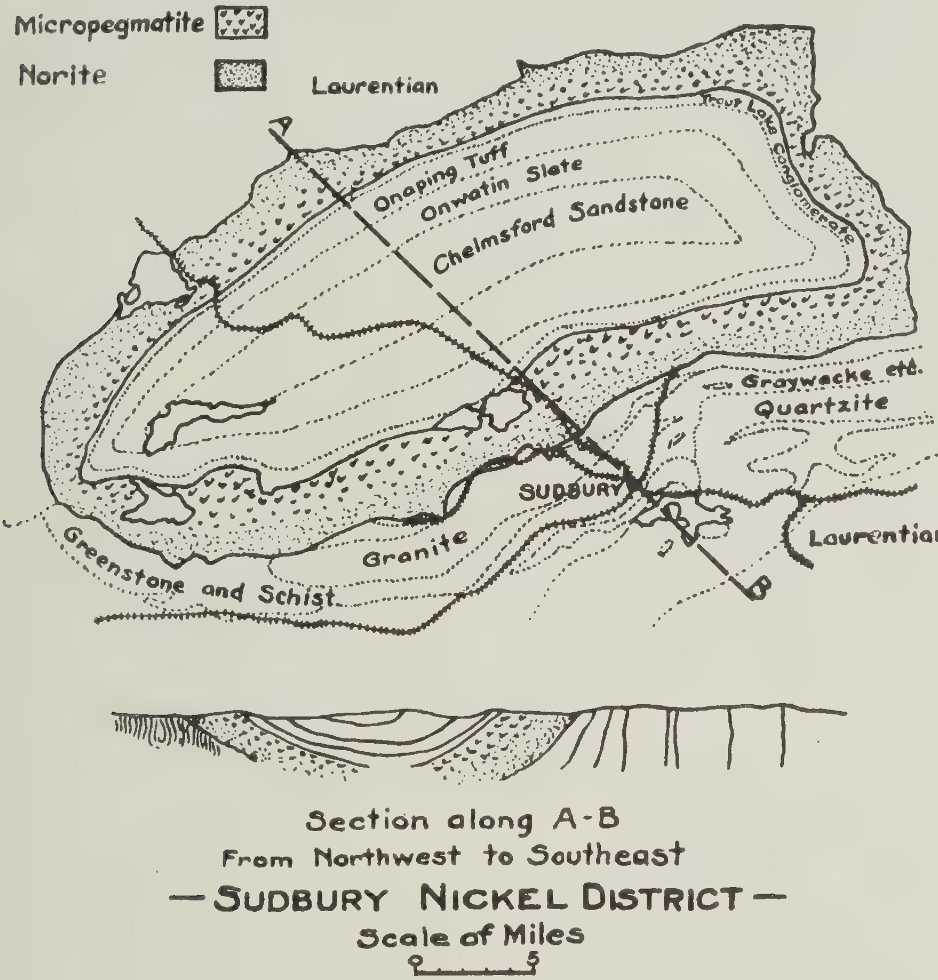

FIG. 68. THE SUDBURY BASIN, ONTARIO

rocks above and probably make the deep-seated sub-structure of great mountain chains.

The dome formed by a batholith may be low with rocks above dipping at small angles away from it, or lofty with the neighbouring rock dipping steeply or even standing vertical. In this case the whole upper part of the structure has often been removed by erosion, disclosing the central parts, usually consisting of coarse-grained granite, granodiorite or diorite.

Within the flatter domes one often finds remnants of the overlying rocks, "roof pendants" more or less metamorphosed by the magma into which they sank.

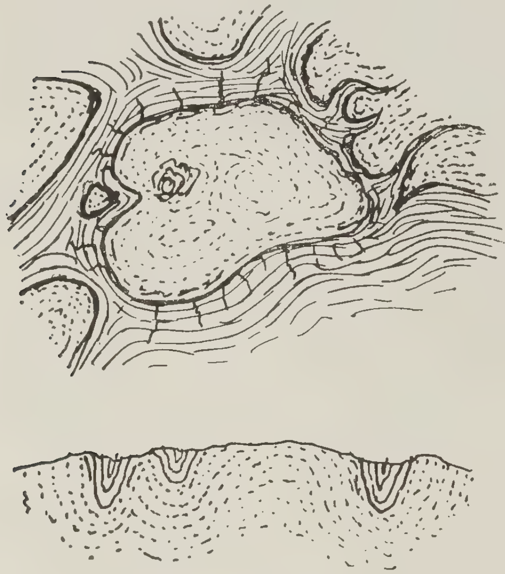

FIG. 69. PLAN AND CROSS SECTION OF A BATHOLITH

The magma of batholiths does not appear to have been very fluid, but from it or from some related source dikes of granite or porphyry generally penetrate the enclosing rocks, which must have been distended and probably fissured by the upwelling of the magma forming the batholith.

Batholiths are the most characteristic structural form of our Canadian Laurentian, covering in all hundreds of thousands or a million square miles of northern Canada with their oval curves, and they make the greater part of the Coast Range of British Columbia.

Stocks or Bosses. Smaller, but still important, masses of eruptive magma seem to have ascended into the overlying rocks without lifting them as domes, perhaps melting their way through and absorbing more or less of the materials encountered. These masses of granite, etc., often resist weathering and stand out as hills when the enclosing rocks have been removed. Stocks may really be the lower parts of volcanic necks in some cases.

Some writers speak of plugs of magma driven up through the strata above as *bysmaliths*; and the term *chonolith* has been suggested for irregularly shaped masses of intruded rock.

JOINTS OF ERUPTIVE ROCKS

Columns. Practically all rocks, sedimentary or eruptive, are parted by joints, but apparently for different reasons, the joints of eruptives being probably due to contraction on

cooling and not to the relief of strains caused by torsion or folding. Fine-grained eruptives, especially the basalts, often have a wonderfully perfect system of contraction joints suggesting the name *basaltic columns.* These columns are about at right angles to the surface of cooling and therefore radiate outwards in volcanic necks, and lie crosswise in dikes and stand vertically in sheets of lava or laccolithic sills.

The columns may be hexagonal in shape, but often have

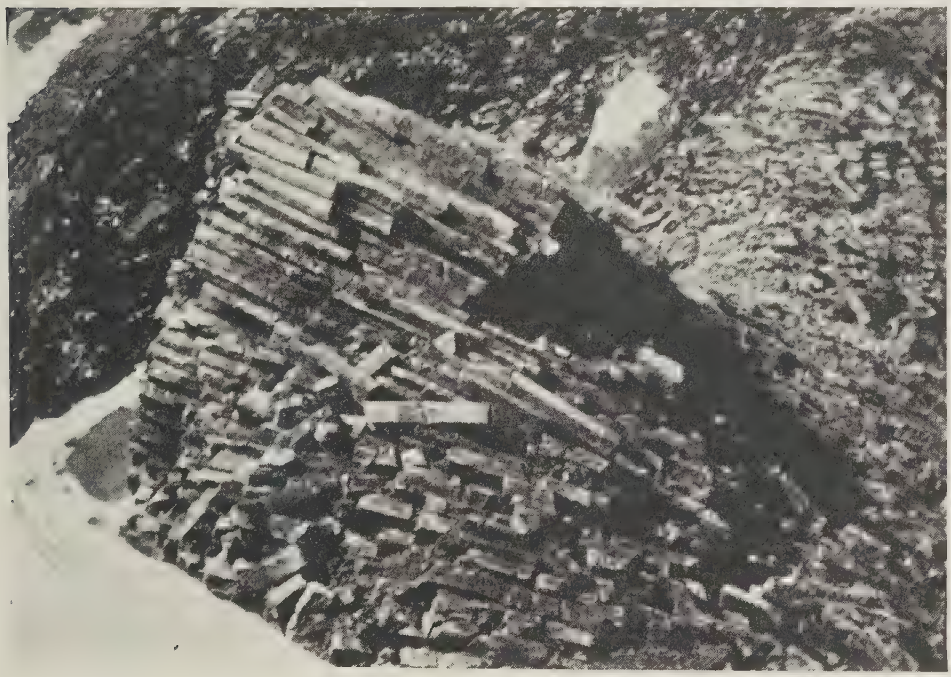

Photo. by E. M. Burwash

FIG. 70. BASALTIC COLUMNS NEAR MOUNT GARIBALDI, B.C.

five, four, or even three sides, or else may have seven or eight. The thickness varies from a few inches to several feet. They are generally broken into segments by a kind of ball and socket joint, and in a dike they may look like a pile of cordwood. Examples may be seen in the diabase dikes and sheets north of Lake Superior, but more perfect prismatic structure is displayed by some of the western lavas. The columns of the Giant's Causeway in Ireland and of the Cave of Staffa in Scotland are famous.

JOINTS OF COARSER-GRAINED ERUPTIVES. The coarser-grained eruptives, such as granite, diorite, etc., show much

less regularity of form and give rise to ruder shapes. In most cases there are joints in three planes, but not always at right angles to one another. In many granites one of the planes is about parallel to the original surface of the cooling mass, giving the effect of banks a few feet in thickness; while the other joints are at right-angles to this direction. The joint fissures may allow water to enter and the angles of the oblong blocks become rounded by weathering, resulting in wool sack-like masses which lie separate from one another and almost suggest drift boulders. This is best seen in unglaciated countries, and is well shown in the Matopos Hills in South Africa and in central India.

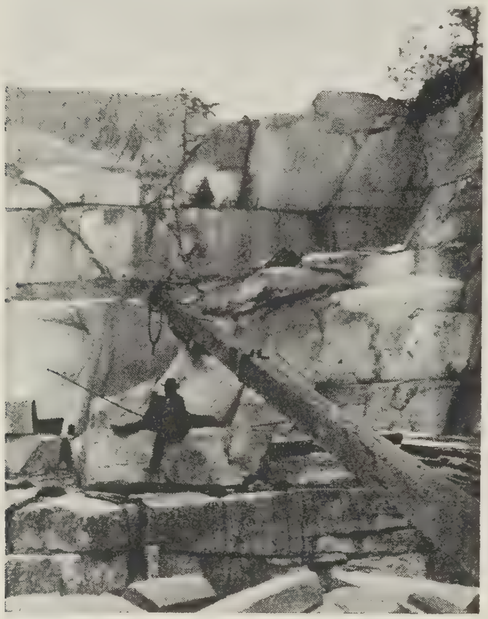

FIG. 71. SHEETING AND JOINTING IN GRANITE, FOX ISLAND, B.C.

STRUCTURES OF SCHISTOSE ROCKS

FOLIATION

Both sedimentary and eruptive rocks may take on the schistose structure, which means literally a cleavable structure, since these rocks can be cleft or split more readily in one direction than in others. This direction of easy division is generally due to the arrangement of certain minerals, especially mica, chlorite, and hornblende, which have their crystals so arranged that the cleavage planes are parallel. Since the very perfect cleavage of the micas and chlorite comes from the thin plates or leaves into which they readily split, the name *foliation* may be given to this arrangement of the schistose rocks.

In the case of gneiss there may be also a banding of different minerals, some layers having more of the light minerals and

others of the dark ones, a very characteristic feature of many Laurentian gneisses. This may be caused by the rolling out of masses of granite penetrated by basic dikes, or by the penetration of thin sheets of granite between the layers of schist, by what is called *lit-par-lit* injection.

Where a porphyritic rock has been sheared and rolled out, the porphyritic crystals, especially feldspars, often resist the pressure better than the other minerals and form *augen* or "eyes," with an unbroken central part and crushed materials tailing out in each direction, the whole forming a bulge in the foliation of the micas above and below.

The schistose structure of some gneisses is the result of a dragging of the minerals into parallelism with the edges of batholiths, as the central, hotter part of the magma continued to push up after the sides had grown cold. On this account one finds rather perfect gneissoid or schistose structure near the margin of batholiths, passing gradually through the form "granitoid gneiss" to granite proper where no parallel arrangement of the minerals can be seen.

Gneissoid and other schistose structures are the prevalent features of the Pre-cambrian of northern Canada, and are usually steeply inclined or nearly vertical, as if the whole series of rocks was on edge. Many of the physiographic features of the region, ridges, ravines, river channels, etc., are bound up with the schistose arrangement of the rock-forming minerals, which has resulted from ancient mountain-building operations.

SLATY CLEAVAGE

A structural feature confined to fine-grained argillaceous rocks, called slaty cleavage, is wide-spread and important in many places. It resembles lamination in unchanged sediments, but has no real relation to sedimentary layers and may cut across the lamination at any angle. Slaty cleavage causes a parting into thin plates or sheets, and is not unlike the more perfect varieties of schistose structure in this respect. It is not the result of the cleavage of micas, however, but is caused by the rearrangement of the small particles of shales by shearing motions under great pressure, the particles swinging so that their longest axes are parallel.

Slaty cleavage may be very persistent in dip and direction over miles of mountain range, as in the Selkirks, and is evidently the result of wide-reaching causes connected with mountain building.

The practical value of this power of splitting into thin uniform plates is shown in the preparing of slates for roofing purposes.

PART II
HISTORICAL GEOLOGY

CHAPTER I

THE MAKING OF THE WORLD

One is apt to think of the world as a finished work like a statue, hewn and polished long ages ago by some great artist and left complete and changeless. We speak of the "everlasting hills" and of "terra firma" as if the present state of things were permanent; and yet we are everywhere surrounded by proofs that the world is not finished, but is constantly undergoing change. The summer rain makes gullies in the fields and carries down mud to the streams; the melting snow in spring turns all the streams to torrents that hurry down mud and sand and gravel and even large stones to the lake or sea; and the frost quarries blocks of the hardest rock from the cliffs, heaping a talus at their feet. If one follows up the work of wind and weather and running water, it soon becomes evident that not alone the hills but all the land that rises above the sea is being constantly attacked and the materials dumped on the sea bottom. If nothing interfered with the process, in time every continent and island would be carved down to sea level, and finally a universal ocean would cover all the world.

This catastrophe has never taken place, however, because there are counteracting forces that lift up the sea bottom in places to make dry land, as one can see on the old marine beaches still containing sea shells hundreds of feet above the Gulf of St. Lawrence in eastern Ontario and Quebec. In many places one even finds ancient sea shells in the rocks of mountain tops.

It is evident that while some forces are tearing down the mountains and devouring the dry land, others are heaving up the surface and rebuilding the hills and mountains; so that

the earth has never been finished, but is still in the making. The earth was not created once for all ages ago and left as finished, but creation is still going on all about us.

Nevertheless, these processes cannot be eternal; they must have had a beginning, and one naturally asks where the materials came from and how they were brought together to form the earth as we know it. In regard to this certain facts are known, and two very interesting theories have been proposed to account for them.

The crust of the earth with its covering of water and air is made up of a large number of chemical elements, and it has been shown by the spectroscope that most of these occur in the sun as well as in the more distant stars. Beside this, the cold solid bodies that come to the earth from space, the meteorites, contain no new elements. They are composed of familiar substances found in the earth, though in different proportions from those of terrestrial minerals. If the rest of the visible universe consists of the same ingredients as our earth, though in the gaseous form owing to heat, and if the dark solid bodies of space also, so far as they reach us, contain only well-known elements of the earth, it is highly probable, if not certain, that the earth has had an origin similar to that of the other bodies in the universe.

It has just been mentioned that bodies made up of intensely hot incandescent gases and also cold and dark bodies exist in space, both composed of the elements found in the earth. One could imagine the earth as beginning either as a mass of hot gas or as a swarm of cold, solid particles compacted together; and both theories have been advocated, the first under the name of the Nebular Theory, and the other as the Planetesimal Theory. An outline of these two hypotheses will be given.

THE NEBULAR THEORY

This theory was first suggested by the philosopher Kant, but was worked out more completely by the astronomer Laplace, and was so simple and beautiful that for many years it was generally accepted as true. Our solar system is supposed to have begun as a vast lens or disc of hot gases containing all

the material of the sun and planets and extending beyond the orbit of the outermost planet. This lens of gas, or nebula, was supposed to be in rotation about a central axis and to be cooling down by the loss of heat into space. As the cooling progressed the lens shrank correspondingly, but the rate of motion remained the same, so that the speed of rotation of the outer parts of the nebula, travelling round a smaller circle, steadily increased. In time the centrifugal force of this outer belt of gas just balanced the gravitational pull of the rest of the nebula and a ring of gas was left behind. This is called *annulation*. Later the material of the ring came together about a centre and rotated about its own axis in the same direction as the parent nebula.

Ring after ring was left behind at definite intervals, and some of the subordinate masses of gas repeated the process on a small scale. The primary spheres of gas condensed to form planets and the secondary ones made satellites like our moon. The vast, central, remaining mass of gas, still incandescent, is the sun; and the sun, the planets, and the satellites with few exceptions rotate in the same direction; while the planets have orbits nearly in the same plane, which is also nearly the plane of the sun's equator. The whole system is steadily cooling; all the inner planets, like our earth, are cold and solid at the surface; the larger outer planets may still be quite hot; while the huge central mass, the sun, still remains intensely hot.

Following the regular course of the hypothesis, our earth began as a sphere of glowing gas extending beyond the orbit of the moon, which was formed from a ring of gas left behind during cooling and contraction. Later the earth became a molten ball with an immense atmosphere, including the present gases and other volatile constituents, such as water and carbon dioxide. The white-hot, molten sphere cooled so far that a solid crust of rock formed, and this at length lost its red heat and reached a temperature where liquid water could exist, collecting in the hollows to form the sea, though still too hot to permit of life. Finally the surface of the earth and the sea upon it became cold, ordinary geological conditions commenced, and lowly plants, and later animals, were introduced, spreading far and wide in the waters.

While the broad outline of the hypothesis seems beautifully simple and attractive and accounts for some well-known phenomena, such as the rise in temperature in depth as shown in mines and bore holes, and the shape of the earth that of a rotating sphere of liquid, yet a careful study brings to light a great number of discrepancies between the theory and the facts of astronomy and geology. Scarcely any of the astronomical features of the solar system agree exactly with the requirements of this hypothesis; the planets do not revolve about the sun exactly in the plane of the ecliptic, as they should, and their axes of rotation are all inclined to it instead of being vertical as one would expect. Some of the satellites revolve in the wrong direction and with an unaccountable speed. A careful mustering of the known nebulæ shows that the annular form is very rare, while many of them have spiral shapes: this does not accord with the requirements of the nebular hypothesis as originally stated. For these and other reasons astronomers find the theory unsatisfactory.

Geologists also have numerous and serious objections to it. If the nebular plan was carried out with anything like exactness, the earth should be a perfect spheroid of rotation with no elevations, such as continents and islands, nor great depressions, such as ocean basins; and the sea should cover the earth's crust everywhere to the same depth, forming a complete hydrosphere, just as there is a complete atmosphere. Again, the oldest known rocks all over the world are sedimentary, *i.e.* they were formed under water; and nowhere do we find any remains of the earth's supposed crust formed by the cooling of the molten sphere. At the very beginning of known geological time there were bodies of water, so that the earth could not have been hot enough to evaporate the seas. Proofs of an ice age at a very early time in the earth's history show that for many millions of years the earth has not been steadily cooling down as the nebular hypothesis demands. Instead of this we know that conditions as to temperature have fluctuated up and down at various times, the changes keeping within such narrow limits that living beings have inhabited sea and land for an immense period of time.

THE PLANETESIMAL THEORY

The fall of meteorites proves that there are cold and solid materials for world building still available in space, and a "meteoric" theory of the origin of the earth was proposed many years ago, according to which a swarm of meteorites moving swiftly and generating heat by their collisions might ultimately combine to produce a molten globe as the starting point for our earth; but this theory has not received much support.

More recently the Planetesimal Theory has been brought forward by Chamberlin, a well-known geologist, and Moulton, an astronomer, to account for the creation of the earth. The word "planetesimal" means a minute planet, a cold particle travelling through space at planetary speed. In essence the theory describes the world as built up mainly or wholly by the coming together of such cold particles under the influence of gravity. The innumerable "shooting stars" which still bombard the earth, coming swiftly out of cold space, shining brightly for a moment from the intense friction with our atmosphere, and then being dissipated to fall as minute particles to the earth, may be looked upon as remnants of the vast numbers of planetesimals which combined to form the earth.

An elaborate process has been suggested to connect the formation of planets with the "knots" of light often observed in spiral nebulæ, but it would lead too far into astronomical speculations to discuss it here. The theory supposes a long period of growth by the accumulation of the planetesimals, the surface of the central sphere remaining cold. Until a size greater than that of the moon was attained, no atmosphere could be held by such a growing world because of its small gravitative power; but ultimately the materials of the air and also of the water of the world would arrive and surround the central-mass. Increasing compression by gravitation would take place as the mass grew and heat would result, with chemical reactions and crystallisation of the compounds formed. Tidal kneading due to the pull of the moon and sun would play a part and radioactive matter coming in with

the planetesimals would produce heat; as a result the interior of the earth would become hot, parts of it hot enough to melt as lava and eruptive rock. Yet the surface of the earth would remain cool enough from the beginning for water to exist in the liquid form and carry on its characteristic work as shown in the stratified rocks.

There is much greater flexibility in the planetesimal theory than in the nebular one, and the suggestion of a world cold from the beginning, perhaps even warming up through the ages, fits much better with the demands of historical geology than the supposition of a molten world slowly cooling through the whole of geological time.

It should be remembered, however, that the planetesimal theory is still under discussion. It must not be looked upon as a proved fact, but rather as the most probable way of accounting for the earth and its history: it may undergo modification as knowledge increases.

CHAPTER II

THE GENERAL PRINCIPLES OF HISTORICAL GEOLOGY

Historical Geology, as the name implies, is simply the history of the earth from the earliest time of which we have evidence in the rocks to the dawn of conditions as we now know them. This history is two-fold; it is at once a record of physical events and an account of the various races of organisms which have inhabited the earth. Incidentally the present position, character, and extent of the component layers of rock form part of the subject of historical geology.

Theories as to the origin of the globe, however useful they may be to the geologist, are not commonly regarded as part of historical geology. We begin with the most ancient actual evidence and trace the history onward from that time.

History, like time, cannot be other than continuous, but even human history has many gaps owing to the failure of a record. In geological history, however, an almost continuous record must have been made, since land and water, with the consequent erosion and sedimentation, have always existed. It by no means follows, however, that we shall ever be able to read the story continuously, because some of the pages may still be under the sea, others hidden by overlying strata, and still others totally destroyed by subsequent erosion. It is evident also that the rock pages of this history are not piled one above the other continuously in any one place, but that the leaves are scattered over the globe, some here and some there. No country, however large and varied, contains within its borders the whole series of strata from the beginning to the present time. It is the business of the geologist to gather together the scattered pages from the whole world and arrange them in chronological order, or, in other words, to decipher the history of the globe.

THE STUDY AND CORRELATION OF STRATA

It is apparent that our knowledge of past events can be acquired only by a study of the rocks themselves. There is

scarcely any fact revealed in the examination of rocks that may not assist in increasing our knowledge of geological history. In order to interpret into history the phenomena exhibited by rocks it is necessary to understand the processes now at work on the globe. For instance, we see the waves on a sandy shore sorting and arranging the grains of sand: when we find sand grains similarly arranged in an ancient stratum of rock we may safely infer that it was formed by wave action near an ancient shore. We see shells being embedded in mud along a coast: when we find similar shells in layers of hard rock we may conclude that that rock was formed at or below sea level, although it may be now thousands of feet above the sea.

Admitting, therefore, that almost any fact revealed by the rocks throws light on their history, it has been found, nevertheless, that certain principles are of especial value in piecing together into a chronological whole the scattered pages of the earth's history. These are:

Superposition. This principle may be briefly stated as follows: the stratum above is younger than that beneath. For instance, in ascending the gorge of the Niagara river we pass upwards from a layer of red shale to a layer of sandstone, to grey shales and limestones, and finally to a heavy layer of dolomite. These various layers correspond in *age* to their *position in the series*, the red shales at the bottom being the oldest and the dolomite at the top the youngest.

Unconformities. When layers of rock lie evenly one on another, as at Niagara, they are said to be *conformable*, and one may conclude that the record is fairly complete; but in many cases the succession is broken by *unconformities* or *discordances* that interrupt the record, as though a leaf or chapter had been torn out of a book. In such a case one finds the lower beds more or less upturned and their edges worn off, while the later rocks rest upon the planed-off surface. In general, one can interpret an unconformity as meaning that the earlier rocks had been tilted or folded and thus raised above the sea, where weather, frost, and running water destroyed the projecting parts; while afterwards the region was lowered beneath the sea again before the later set of sediments was deposited. It is evident that these processes

require time for their accomplishment, so that a marked discordance means a very considerable gap in the record.

Beneath some of our older formations one finds a surface with structures corresponding to the base of a great mountain range, and one can infer an astonishing series of changes, where rocks laid down on a sea bottom have been bent up into domes or folds thousands of feet high and penetrated by dikes or masses of molten granite. Then the whole vast chain has been slowly attacked and carved down by superficial forces until the surface has been levelled almost to a plain. Finally the later sheet of sediment has been laid down on the upturned edges of the ancient structures. Such a discordance undoubtedly implies an interval of long ages, probably many millions of years. What happened during the vast interval is recorded only negatively by the mountain stumps that remain outlining the foundations of the huge structures destroyed by "the tooth of time" while the region stood above the level of the sea.

Unconformities are generally distinct and easily recognised when any considerable area is studied; but occasionally there is no angular break between the two series of rocks, so that one could imagine them to form a continuous succession. In such *disconformities*, as they may be called, the older rocks have usually been more or less cut by valleys, which have been filled in by the later sediments.

Basal Conglomerates. Where an upper series of rocks begins with coarse materials, forming a "basal conglomerate," the break is instantly evident, even if no unconformity of angle is to be seen between it and the lower series. Such a conglomerate, made up of fragments of the bed beneath, proves that the lower series had been consolidated into firm rock and had then been broken up, the angular fragments being rounded by currents or waves or even by glacial action before the materials were worked up into the later formation. All these requirements mean the lapse of time. If pebbles or boulders of several kinds of rocks derived from different sources occur in the basal conglomerate, the destruction of the older series must have been widespread and the time interval probably long.

Where two or more unconformable series of rocks have

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been folded, squeezed, and rolled out in mountain building, the planes of discordance may become unrecognisable and the separation of the formations may be difficult or impossible. Basal conglomerates, however, even if the pebbles are rolled out into lenses, may give much help in disentangling the relations if their materials are well enough preserved to determine the beds from which they were derived. Where the rolling out has gone to the extreme, as in some schistose rocks, even the pebbles of conglomerate disappear, and there is often no clue to the order of succession.

Lithological Characters. Where other more satisfactory means of working out the succession of the rocks are not available, one may make use of the actual nature of the rocks themselves. If rocks at different places are alike it is natural to think of them as formed under the same conditions and at the same time, and sometimes one can actually follow a particular rock from point to point with little or no change, thus proving positively that two widely separated outcrops are continuous with one another and therefore of the same age.

There are cases, however, where one can begin with one rock, such as sandstone, and end, perhaps miles away, with another rock, such as shale. These two rocks were evidently formed at the same time and in the same body of water, but under different conditions, sand being deposited at one place and mud at another, and a mixture of the two at intermediate points. This shows that the lithological method of correlating rocks at a distance from one another must be used with caution, particularly when one remembers that similar conditions resulting in similar rocks have recurred again and again in the earth's history.

Fossils. Except in the very oldest rocks, the evidences of the existence of plants and animals are of the highest value in working out the orderly succession of the strata and in correlating the rocks of one locality with those of another. In addition, the history of the organisms which have inhabited the globe is, in itself, a part of historical geology and goes hand in hand with the record of physical events to make up the history of the earth.

We do not know when life began on the earth, and it is

doubtful if we ever shall know. Evidences of the existence of organised beings have been found in very old rocks, but not in the most ancient rocks of all. Whether or not animals or plants inhabited the globe in this very early time, who shall say? In the science of geology negative statements may sometimes be made with certainty; generally, however, such statements are intended to express only our present knowledge of the point in question. Particularly with regard to the history of life one must remember that statements as to the non-existence of certain animals at certain times mean only that evidences of their existence have not been found.

We know that organised creatures have inhabited the globe continuously from the time of their first appearance to the present. We know that life has changed, one group of organisms being succeeded by another in orderly succession throughout the geological ages. We know that the older an organism is the more it differs from creatures now living. Finally we *infer*, on very substantial grounds, that these different races of organisms have not been separately created, but that the younger has descended from the older by a process of organic evolution.

The concrete evidences on which the above assertions are made are known as *fossils*, and that branch of geological science which deals with this evidence is *palæontology*. One should avoid the popular conception of a fossil as the remains of an *extinct* organism, or the equally erroneous idea that a fossil is something petrified or converted into stone. Anything found in the rocks that indicates indubitably the existence of an organism in time earlier than the Recent is a fossil. Among the more obvious fossils are shells, in the natural condition or altered into some other substance (petrified), teeth, spines, scales, bones, wood, spores, seeds, and in rare cases even flesh and hair. Less obvious, but just as truly fossils, are moulds and casts of shells or other parts of creatures, impressions of leaves, footprints, borings, burrowings, and excrements. A shell found buried in the sand or mud on the shore of Lake Ontario is not a fossil; but the same shell found in the same vicinity but in a stratum of sand or mud not formed by the present Lake Ontario is a fossil. Fossils, therefore, do not necessarily represent extinct organisms.

The number of known fossils is enormous; hundreds of thousands of different creatures have inhabited the globe throughout the geological ages. The history of these creatures, their habits, their evolution, their migrations, their battles for supremacy, their rise and fall constitute a large part of historical geology.

The time during which a creature is known to have existed is called its *range*. Some fossils have a short range and others a long range. Naturally the long-range forms belong to dominant races represented by great numbers of individuals: such forms are worthy of especial mention in recounting the history of their time. Short-range forms are usually represented by fewer individuals, and they may be confined to a single formation or even to a single stratum: these are less worthy of mention in a general account of the life of their time. On the other hand, they rise to the highest rank of importance in the eyes of the professional geologist. The very fact of their short range enables him to regard them as "thumb marks" of the stratum to which they belong and renders them of inestimable value in fixing the relative age of the associated strata.

The rocks of the Niagara gorge, already used as an example, contain some long-range and some short-range fossils: the former are interesting in that they indicate the general life of the time, but the latter are like dates on a coin, fixing the age of the rock which contains them. If we find an isolated bed of rock, perhaps miles away, containing the same fossils as one of the beds at Niagara, we are justified in concluding that it is of the same age as the corresponding bed there.

Unfortunately many rocks, particularly the older ones, contain no fossils, so that other methods must be used to determine their age. Where the succession of the rocks has been worked out on a physical basis, fossils may be used to supplement the conclusions arrived at: for instance, the fossils below and above an unconformity are unlike, and the greater the unconformity the greater is the difference in the fossils. In the case of a disconformity, the fossils below and above the break are usually different, but not extremely so. A difference in the fossils may lead a geologist to suspect the existence of a disconformity, and the discovery of a

disconformity will lead to a careful search for fossils as corroborative evidence.

Even where the succession of the different beds of rock is continuous one cannot always be sure of their order in time. Where a fold has been closed and its upper part carved away, leaving the two sides pressed together and vertical, there are often puzzling relationships; and where a succession of strata has been overturned in mountain building, the lower beds may be younger than the upper ones. There are even cases where ancient rocks have been pushed bodily over much younger rocks, so that the overlying bed may be millions of years older than the one beneath, as in the thrusting of ranges of the Rocky mountains over the foothills in southern Alberta.

It is evident then that the correlation of the rocks of different regions, where the evidence of fossils is wanting, presents many difficulties; so that the relations of the ancient crystalline rocks without fossils can seldom be worked out with as much certainty as those of later ages. Since more than half of Canada consists of these ancient rocks, it is evident that we have one of the most difficult regions to study in this respect; but the greatness of the area and the unusually good exposures of the rocks give probably the best opportunity in the world for working out their relationships.

Even when working on fossiliferous formations one must remember that the record available is usually that of the sea bottom only. Marine plants and animals which have hard parts may be very well preserved, but there may be little evidence of conditions on the land. The record of the inhabitants of the land, especially in the older periods, is usually wanting and is always very meagre. A leaf or a piece of wood waterlogged and buried in the mud, or a few bones or a feather brought down by some stream, may be all that remains to us of the plants and animals of a continent.

At the present time rocks are being formed under very different conditions in different parts of the world. In the deeper parts of the sea, organisms are being entombed which do not exist in the shallow waters along the coast; Arctic organisms are entirely different from those of the Torrid Zone; the freshwater shells which accumulate on lake bottoms differ from the marine shells of the ocean; swamps and lagoons

are inhabited by creatures not known in the open sea. It is apparent, therefore, that, at the same time, very different rocks containing very different organisms are being formed. These varying sets of conditions are known as *facies*; thus we have marine, freshwater, pelagic, littoral, and other facies. There is no reason to doubt that conditions of sedimentation varied as greatly in geological time as they do at present, consequently we may expect to find strata of different facies throughout the geological record. At once we are confronted by an added difficulty in deciphering the geological history of the earth, but as the record left by marine organisms is the most continuous, we rely on that almost entirely for the subdividing of rocks and time. Strata of facies other than marine are fitted into the geological column by whatever accessory evidence is available.

While marine deposits rank first in importance, there are, however, some land deposits preserved on a large scale, giving clear evidence of what took place on the continents; such as desert formations and glacial "tillites" or ancient boulder clays. A red, irregularly bedded sandstone may be clearly the work of desert winds, though now thousands of miles from the nearest arid region; and one may find striated stones in tillites within the tropics on several continents, proving the former existence of great ice sheets where now frost is unknown. The growths in low-lying swamps, also, may be preserved by a sinking of the land allowing marine deposits to cover them, and sometimes an old soil with the trunks of trees may be sealed up in the same way.

THE SUBDIVISIONS OF GEOLOGICAL TIME

The preservation of land deposits is very infrequent in the older rocks and by no means common in the later ones, so that our time scale depends mainly on the sediments of the sea. Since the inhabitants of the sea have often left their shells or other hard parts to be studied by the palæontologist, the broad divisions of geological time are usually made in accordance with the character of the marine life of the different eras. Thus, in most works on geology, the world's history is divided into grand subdivisions on the basis of life.

We distinguish the *Palæozoic*, or time of ancient life, the *Mesozoic*, or time of middle life, and the *Cenozoic*, or time of recent life; and some geologists place a *Proterozoic* before the Palæozoic, and even an *Archæozoic* before that, although we know very little of the life of the world before the beginning of the Palæozoic.

In former times a numerical classification was employed, the oldest rocks then known being the *Primary*, the Mesozoic the *Secondary*, and the Cenozoic the *Tertiary*. While the terms "Primary" and "Secondary" have entirely fallen into disuse, the term "Tertiary" is still employed for a division of the Cenozoic. Frequently the whole time before the Palæozoic is included under the term *Archæan*, meaning simply "ancient," but in the latest works the rather clumsy expression *Pre-cambrian* is made use of for the time before the first distinctly fossiliferous formation.

Just as a day is divided into hours, and an hour into minutes, etc., we require corresponding terms for our subdivisions of geological time, but it is evident that the same terms will not apply both to a division of time and to the corresponding division of the rocks made during that time. For instance, we may speak of a subdivision of time as an *era*, but we cannot call a division of rocks an era. Much confusion has arisen in the use of terms for the various subdivisions of rocks and time. In an attempt to standardise the method of nomenclature the International Geological Congress proposed the following system:

Time Terms	Rock Terms
Era	Group
Period	System
Epoch	Series
Age	Stage
	Substage
	Zone

Unfortunately, this system has not been universally adopted, perhaps because the familiar expression "Formation" is not included. The system employed by the Geological Survey of Canada is as follows:

Time Terms	Rock Terms
Era	
Period	System
Epoch	Series
Stage	Formation
	Member

In this method of nomenclature the word "Group" is not used in a definite sense as the rock equivalent of "Era," but it is employed to designate an assemblage of strata the exact subdivisions of which may be unknown or in doubt.

Geological time, therefore, is divided into grand divisions, eras; the eras into periods; the periods into epochs, etc. In order to distinguish between the different eras, periods, and minor divisions, it is necessary to give a *name* to each of them. In coining such names it is now the universal practice to use only geographical terms; thus, *Onondaga* stage if speaking of time and *Onondaga* formation if speaking of the rocks. In the early days of geological science this method was not employed, and in consequence many terms were introduced which are not in accord with the geographical method of nomenclature. As already stated, the greatest divisions of all are based on life terms, *Palæozoic, Mesozoic,* etc., and others, such as *Carboniferous,* on the character of the rock itself.

Strictly speaking, the name of an era or other division of either time or rocks is a proper adjective and should be followed by the noun "era," or whatever term is appropriate. In practice, however, it is customary to omit the noun and to write "the Palæozoic," "the Silurian," without introducing either the time or rock term.

Geology is a progressive science, with new discoveries constantly being made, and with new points of view constantly being set up; in consequence, it is not surprising that authors differ in their method of classifying rocks and time. No two men in writing a history of human events would divide their matter similarly into books, chapters, etc. Is it to be expected that the much more complex history of the earth will impress all observers in exactly the same way? At the end of this chapter a table is given which indicates the method of classification employed in this book.

The age of eruptive rocks may be determined in most cases by their relationships to sedimentary formations. Lava streams or beds of volcanic ash lying between two sedimentary rocks are evidently of intermediate age, and any eruptive mass that penetrates sedimentary beds is clearly of later age than those beds. Where eruptive rocks cover large areas to the exclusion of sediments, and where there have been eruptions at different times and of different kinds, the age relations become more complex; but often one can work out a succession of events, one eruptive penetrating an earlier one as bosses or dikes, thus disclosing the relative age.

Where, however, the region has been acted on by mountain-building forces and has suffered metamorphic changes, transforming the original massive rocks into schists and gneisses, the order of succession is much more difficult to unravel. The great developments of granite and gneiss in northern Canada, often out of reach of any sedimentary rock to indicate the time scale, provide very difficult problems to solve, since the granites and gneisses of one period may be very much like those of another, as in the case of the so-called Laurentian and Algoman rocks.

Eruptives are sometimes looked on as accidental features and are not included in the general time scale founded on the succession of sedimentary rocks, but where they cover great areas, as in Canada, the problem of their age and relations to the sediments cannot be passed over despite the difficulty of working them out.

In the table on the following page the names printed in italics are used only in America.

Table Showing the Main Divisions of Geological Time

	Era	Period	Epoch
	Cenozoic Era	Quaternary	Pleistocene
		Tertiary	Pliocene Miocene Oligocene Eocene Palæocene
	Mesozoic Era	Cretaceous: *Cretaceous*	Upper Cretaceous
		Cretaceous: *Comanchian*	Lower Cretaceous
		Jurassic	Upper Jurassic Middle Jurassic Lower Jurassic = Liassic
		Triassic	
	Palæozoic Era	Permian	
		Carboniferous: *Pennsylvanian*	Upper Carboniferous
		Carboniferous: *Mississippian*	Lower Carboniferous
		Devonian	Upper Devonian Middle Devonian Lower Devonian
		Silurian	Upper Silurian = *Cayugan* Middle Silurian = *Niagaran* Lower Silurian = *Oswegan*
		Ordovician	Upper Ordovician = *Cincinnatian* Middle Ordovician = *Champlainian* Lower Ordovician = *Canadian*
		Cambrian	Upper Cambrian = *Croixian* Middle Cambrian = *Acadian* Lower Cambrian = *Waucobian*
Archæan or Pre-Cambrian	Proterozoic Era	Late Proterozoic	Keweenawan Animikie Huronian
		Early Proterozoic	Algoman Sudburian or Timiskamian
	Archæozoic Era		Laurentian Keewatin and Grenville

CHAPTER III

THE NOMENCLATURE AND CLASSIFICATION OF ORGANISMS

THE history of the development of life on the earth is intimately connected with the record of physical events. The study of fossils is a part of geological science necessary for the historical account and of practical value in working out the sequence of the rocks.

Fortunate is the beginner in geology who has a knowledge of the sciences of zoology and botany, for fossils are closely related to the animals and plants now inhabiting the earth. So close is this relationship that the methods of study used in zoology and botany are equally applicable in the case of fossils. The organisms of the past are links in one great chain of life, and they may be fitted into any scheme of classification that includes all living creatures.

To the practical geologist the ability to recognise a fossil on sight is of the first importance. He does not require a *name* in order to fix the fossil in his memory, but in order to speak or write of it some short and definite designation is necessary. Many living creatures have popular names, but fossils, being little known except to scientists, have not acquired names of that kind. In consequence the scientific method of nomenclature is used almost entirely for fossils.

The individual organism, animal or vegetable, living or fossil, is known as a *species* and is given a name; for instance, the American elm is called *Ulmus americanus*: the latter word "americanus" refers only to this species, but the former word "Ulmus" is applied to other kinds of elm and is followed by a second word to indicate the species. In other words, all the different kinds of elms belong to the *genus* Ulmus, but only the American elm is *Ulmus americanus*. This system of naming is quite the same as that used for persons, except that the order of the two names is reversed. John Smith would become Smith John if written according to the usage of scientists.

This method of naming indicates also the fundamental principle underlying the classification of organisms. The species *Ulmus americanus* is an individual plant, but all related forms are included in the genus *Ulmus*. Similarly, related genera are grouped together in *families*, families in *orders*, orders in *classes*, etc. Classification, therefore, serves two main purposes: it enables us to speak and write of organisms without the constant use of long explanations, and it indicates the relationships that exist among the various kinds of creatures.

It is obviously impossible in an elementary work on geology to attempt anything like an adequate description of the various kinds of organisms; nevertheless, the student should realise that a knowledge of organisms is an essential part of geology. On the other hand, lest the beginner be discouraged, he should remember that many eminent geologists have only a general knowledge of fossils: in these days of specialisation they turn to the palæontologist for a solution of those problems which demand an intimate knowledge of fossils.

In this work a short description of the different important groups of fossils will be given in the historical account, at the times when they first appear. The following brief synopsis of the classification of organisms contains only those groups of creatures of importance in geological history. The student is advised to make use of this table for reference when he is reading the accounts of fossils given on later pages.

AN OUTLINE OF THE CLASSIFICATION OF ORGANISMS

ANIMAL KINGDOM:

Sub-kingdom INVERTEBRATA. Animals without backbone.

Branch PROTOZOA. Animals of one organic cell only.

Order FORAMINIFERA. Small animals with delicate shell of carbonate of lime.

Branch CŒLENTERATA. Animals with a single body cavity for all vital functions.

Class SPONGIÆ. Pores through the wall of the body; skeleton of spicules of lime, silica, or horny matter.

ANTHOZOA. The corals. Body wall without pores.

HYDROZOA. Resemble corals but are smaller and differ in some details.

Order GRAPTOLITOIDEA. Extinct order. See page 206.

STROMATOPOROIDEA. Extinct order. See page 224.

Branch ECHINODERMATA. Animals covered with plates of carbonate of lime; water vascular system present.

Class CRINOIDEA. Plated body or cup attached to the sea floor by a jointed stem; circlet of waving arms above.

CYSTOIDEA. Resemble crinoids but with less development of arms. Plates sometimes porous. Extinct.

BLASTOIDEA. Resemble crinoids but have bud-shaped bodies and plumes instead of waving arms. Extinct.

ASTEROIDEA. Free-swimming star fishes; not attached to sea floor; mouth downward; star-shaped bodies.

ECHINOIDEA. Free-swimming sea urchins; body spherical or cake-shaped, cardiform, etc.

Branch VERMES. The worms. Bilateral, elongated animals, segmented or unsegmented.

Class ANNELIDA. The segmented worms. Body composed of a number of joints. Seaworms, earthworms, etc.

Sub-order TUBICOLA. Inhabiting calcareous tubes.

ERRANTIA. The free-swimming, marine worms.

Branch MOLLUSCOIDEA. Animals with short, simple alimentary canal; respiratory organs in front of mouth.

Class BRYOZOA. Very small organisms living in colonies and secreting a compound skeleton resembling that of corals.

BRACHIOPODA. Much larger than Bryozoa; not in colonies, but single; secrete a bivalved shell each valve of which is symmetrical about a median line. See page 208.

Branch MOLLUSCA. Bilateral, highly developed organisms with heart and systemic circulation; body enclosed in mantle; fleshy foot-like structure on under side; shells differ in the different classes.

Class PELECYPODA. Known also as Lamellibranchs and Bivalves; include such creatures as the common clam, oyster, etc. Foot hatchet-shaped; gills usually leaf-like.

SCAPHOPODA. With long, tapering, tubular shell.

GASTROPODA. Shells single, hence called Univalves; shells saucer shaped or spiral; foot a creeping or swimming organ. Snails and related creatures.

CEPHALOPODA. Highly developed molluscs. Edges of foot rolled up to form a tube through which the water from the gill cavity is ejected. Squids, nautilus, cuttle-fish, etc.

Order NAUTILOIDEA. Free-swimming marine organisms with straight or coiled shells. The shells are divided into chambers by simple partitions.

AMMONOIDEA. Like Nautiloidea, but the edges of the partitions are puckered so that their union with the shell wall is not simple but complicated. Extinct.

BELEMNOIDEA. With a cigar-shaped internal shell. Belemnites proper are extinct.

Branch ARTHROPODA. The higher invertebrate animals with jointed legs.

Class CRUSTACEA. Breathe by gills; generally aquatic; many limbs and segments.

Sub-class TRILOBITA. Crustacea with only one pair of antennæ and a very characteristic three-lobed body.

EUCRUSTACEA. Two pair of antennæ; non-trilobite body.

Super-order PHYLLOPODA. Elongated body, laterally compressed shell.

OSTRACODA. With bivalved shell covering the whole body.

CIRRIPEDIA. The barnacles, etc.

MALACOSTRACA. The higher crustaceans with a constant number of segments, 20 or 21.

Order SCHIZOPODA. Eyes on movable stalks.

DECAPODA. With ten feet; lobsters, crabs, etc.

Class ACERATA. Body divided into two regions; breathe by lung-books.

Sub-class MEROSTOMATA. The king crabs and related forms.

Order EURYPTERIDA. A group of peculiar extinct organisms. See page 230.

Sub-class ARACHNIDA. The spiders, scorpions, mites, etc.

Sub-branch MYRIOPODA. Long-bodied, wingless arthropods breathing by tracheæ. The thousand-legs, etc.

INSECTA. The insects.

Sub-kingdom VERTEBRATA. Animals with backbone.

Class AGNATHA. Fish-like forms but without jaws.

PISCES. The fishes. Long-bodied, aquatic; breathe by gills.

Sub-class ELASMOBRANCHII. Cartilaginous fish with several gill clefts. Sharks, rays, and various extinct groups.

HOLOCEPHALI. The chimeras, etc.

DIPNOI. The lung fishes.

TELEOSTOMI. Ganoids and scaly fishes.

Order CROSSOPTERYGII. With fringed fins.

ACTINOPTERYGII. With shortened fin axes and long rays.

Class AMPHIBIA. Broad-headed animals without external scales or plates; undergo a metamorphosis.

Order STEGOCEPHALIA. Extinct forms with plated cheeks.

Class Reptilia. Cold-blooded animals with no metamorphosis.
 Order Anomodontia. Primitive extinct forms.
  Sauropterygia. Long-necked, extinct, aquatic reptiles.
  Chelonia. The turtles.
  Ichthyopterygia. Short-necked, extinct, aquatic reptiles.
  Rhynchocephalia. Primitive type of land reptile.
  Squamata. Elongated forms like the snakes and some extinct water reptiles.
  Dinosauria. A great group of extinct land reptiles.
  Crocodilia. Crocodiles, alligators, etc.
  Ornithosauria. Extinct flying reptiles.

Class Aves. The birds.
 Sub-class Archæornithes. Peculiar extinct birds with teeth.
  Neornithes. All other birds.
 Order Ratitæ. Flat-breasted birds without the power of flight.
  Carinatæ. Flying birds, with a crest on the breast bone.

Class Mammalia. The mammals. Warm-blooded animals; suckle the young.
 Sub-class Prototheria. Oviparous.
  Metatheria. Young born immature and carried in a brood pouch. Kangaroos, etc.
  Eutheria. Young capable of independent existence.
 Order Cetacea. Whales.
  Sirenia. Manatees and dugongs.
  Edentata. Ant-eaters, armadillos, and extinct forms.
  Ungulata. The hoofed animals. Horse, cattle, deer, elephant, etc.
  Rodentia. The rodents. Beaver, hedgehogs, rats, etc.
  Carnivora. The predaceous, flesh-eating mammals.
  Insectivora. Shrews, moles, etc.
  Chiroptera. Bats.
  Primates. Lemurs, monkeys, man.

VEGETABLE KINGDOM:

Sub-kingdom Cryptogamæ. The lower plants in which reproduction is effected by means of spores.
 Branch Thallophyta. Unicellular or multicellular plants of simple construction. The larger forms grow as flattened expansions which do not show root, stem, and leaves as in the higher plants.
  Class Algæ. Includes unicellular organisms of microscopic size (diatoms and desmids), the red and brown sea weeds, and the freshwater green and blue-green weeds.
   Fungi. The funguses. No importance as fossils.
 Branch Bryophyta. Spore-bearing plants composed of cellular tissue which shows little differentiation. By sexual reproduction a spore-case arises in which the spores are asexually produced. Mosses and liverworts, of little importance as fossils.

PTERIDOPHYTA. The tissue is not evenly cellular throughout the plant, but is partly differentiated into special tissue which forms longitudinal bundles and facilitates the transmission of fluids. On this account the pteridophytes are called "vascular cryptogams." Ferns, horsetails, and club mosses.

Sub-kingdom PHANEROGAMÆ. Plants that reproduce by means of seeds.

Branch GYMNOSPERMÆ. The most lowly of the flowering plants. Primitive forms are scarcely to be distinguished from the highest pteridophytes. The name means "naked-seeded," and is derived from the fact that the seed is not enclosed in the ovary.

Class CYCADALES. These plants fade into the pteridophytes on the one hand, and less clearly into conifers on the other. Most existing cycads have short trunks which bear a crown of leaves resembling those of a tree fern. The bark is marked by numerous leaf scars. The leaves are large, pinnate, and of firm structure. A cross section of the stem shows many variations, but always there is a large amount of pithy tissue often alternating with rings of wood. These plants are one of the sources of sago, which is stored in the pithy tissue. Fossil cycads are of great importance: they are known principally from leaves, but also from trunks and fruits.

GINKOALES. Resemble cycads in the method of fertilisation. The foliage resembles that of the maidenhair fern; they are called "maidenhair trees" in consequence.

CONIFERALES. Unlike the cycads these trees form long tapering trunks from which branches arise, either in whorls or irregularly. In both cases the general effect of the branching is to produce a tree of tapering, cone-like outline. The leaves are always small, frequently elongate; in this respect the conifers differ strikingly from the cycads.

Branch ANGIOSPERMÆ. The true flowering plants in which the seed is enclosed in an ovary.

CHAPTER IV

THE ARCHÆAN OR PRE-CAMBRIAN

WHEN geologists first attempted to work out the history of the world they naturally began with the rocks at hand in England, France, or Germany: it was found that these rocks contained sea shells and that they had clearly been laid down on the sea bottom. It was presently found that the most convenient way of classifying them was by the character of the life of the time as shown by the fossils, and gradually a scheme of classification grew into shape in which the history of the world was divided into great divisions, each with its own types of life.

The lowest division was called the *Palæozoic*, or Time of Ancient Life (from the Greek words *palaios*, ancient, and *zoön*, an animal). Following the succession of formations downwards in the Palæozoic, the lowest beds containing fossils were named the *Cambrian*, and for a long time investigation practically stopped at that limit. The rocks below were not alone void of fossils, but often had such confused and complicated arrangements that they seemed quite hopeless and were set aside in despair as a "basal complex" or "fundamental complex." Something had to be done with them, however, in the classification, and since they showed no evidence of life they were called *Azoic* (without life), to bring them into line with the "zoic" system.

Doubts arose, however, as to the real absence of life in these older times because of the apparently sudden appearance of the multitude of animals that swarmed in the Cambrian sea; in consequence, some geologists suggested the name *Eozoic* (dawn of life). As a compromise between the two hostile views many writers used the term *Archæan* (ancient), which implies no theory, and others the negative expression *Pre-cambrian*. Both are still in good use.

It is not surprising that the classification of the troublesome rocks below the Cambrian should long have been neglected in

Europe, since only small and scattered areas of them exist in the countries where geology was earliest cultivated, and the succession in Europe is very incomplete, except apparently in Finland. Even in Canada, with the largest and best exposed Pre-cambrian area in the world, there are still difficulties in the classification, especially of the older and more metamorphosed parts.

The first serious attempt to subdivide the basal complex was made by a Canadian, Sir William Logan, first Director of our Geological Survey. He found a great thickness of steeply tilted, crystalline rocks, mostly gneisses, underlying all others along the St. Lawrence valley, and named them the *Laurentian*. He divided the Laurentian into a lower part, the *Ottawa gneiss*, and an upper part, the *Grenville* series, supposed to be the younger of the two. Above rocks of this kind, on the north shore of Lake Huron, a series of comparatively flat-lying and unchanged sediments was named the *Huronian*.

For a long time this classification of the Pre-cambrian was accepted as sufficient, not only in North America, but also in Europe.

Later the name *Keewatin* was given to rocks west of Lake Superior which had been included in the Huronian, but were proved by Dr. Lawson to be older than the Laurentian, and therefore far older than the original Huronian.

Still later it was found that a great series of sedimentary rocks, younger than the Keewatin and Grenville series, but older than the Huronian, existed near Lake Timiskaming, at Sudbury and elsewhere. The gaps between these rocks and those above and below are profound, great enough to allow time for the elevation and destruction of mountain chains, so that it was necessary to place them in a division by themselves.

The final result is the classification given on page 154, which may, however, have to be revised in later years as our knowledge of these obscure, half-obliterated pages of the earliest history of Canada and the rest of the world grows more complete.

In all the older writings on the geology of Canada, the whole of the Pre-cambrian is included under the term Archæan; but some American geologists use it only for the Pre-huronian series, and put the Huronian and later series into the *Algon-*

kian. This usage has not been adopted in Canada except, sometimes, for parts of the western Pre-cambrian.

The terms *Proterozoic* and *Archæozoic* are used by some good authorities to express ancient life relationships which almost certainly existed, but of which there is little direct proof.

In the account of the Archæan formations we shall disregard the subdivision into Proterozoic and Archæozoic and begin with the oldest known formations, the Grenville and

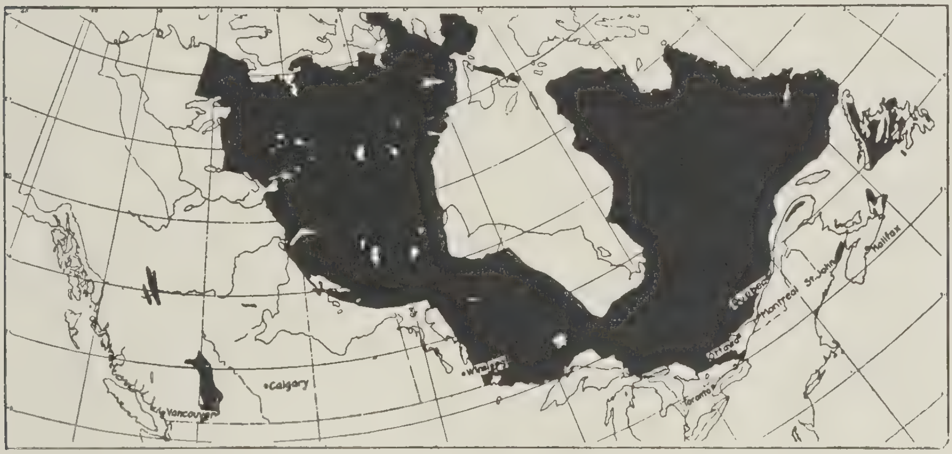

FIG. 72. OUTLINE MAP OF CANADA SHOWING IN BLACK THE CHIEF AREAS OF PRE-CAMBRIAN ROCKS

Note the "Canadian shield" surrounding Hudson bay and the smaller areas to the east and west.

Keewatin, as shown in the table on page 154. To these a third series will be added, the *Coutchiching.*

THE GRENVILLE SERIES

Logan considered the Laurentian (Ottawa gneiss) the oldest of the Canadian rocks, since it underlies all others, and believed that it consisted of metamorphosed sediments, the banded structure commonly observed in gneisses being looked on as evidence of stratification. It has been proved, however, by later field work, especially since the petrographic microscope came into use, that the granites and also most of the Laurentian gneisses are eruptive masses, batholiths which have domed up the Grenville series of the east and the

Keewatin of the west, sending dikes into them and splitting off and carrying away fragments. It is certain, therefore, that these underlying granites and gneisses are younger than the overlying rocks, since the age of an eruptive rock is reckoned from the time when it cooled.

Accordingly the Grenville and the Keewatin, probably of about the same age, are the earliest of known rocks. As the Grenville was studied first it may take precedence of the Keewatin.

The most striking Grenville rock is crystalline limestone, sometimes white, like coarse marble, but often grey or coloured, and sometimes charged with minerals such as graphite, mica, hornblende, augite, or serpentine. As this is the least resistant rock of the series it is usually found in valleys and makes the bed of rivers or lakes.

Along with the crystalline limestone and sometimes interbedded with it, one generally finds gneiss or quartzite, the former often containing pyrite, garnet, and graphite, while the latter is generally glassy and more or less mixed with garnet, feldspar, or other silicates.

The gneiss of the Grenville differs markedly in most cases from the Laurentian gneiss, which is really a schistose granite: it is often duller in colour, weathers rusty from the decay of the pyrite, and may contain graphite or sillimanite, which are not found in Laurentian gneiss. Analyses show that it has the composition of a slate or shale.

The quartzite of the Grenville is not so widely found as the other rocks, but is well seen at the Thousand islands.

Schistose conglomerate is occasionally mentioned as a rock of the Grenville series, but it may really be a basal conglomerate of a later formation and will not be described here.

Most of the Grenville rocks, in spite of their crystalline or schistose character, are really sediments, evidently water-formed as sand or mud or limey materials, exactly as sediments have been laid down in all the later ages of the world; and it is astonishing to find this earliest of formations presenting in a disguised form all the common kinds of stratified rocks. There are even suggestions of life in the graphite, the carbon of which may have come from primitive plants, and the calcite

of the limestone which may have been formed of the hard parts of animals.

At one time it was believed that a peculiar interbanding of calcite and serpentine was a fossil protozoan which received the name of *Eozoön canadense*, the Canadian "dawn animal"; but there is proof that this is a mistake, so that the evidence for life in the Archæozoic does not go beyond the carbon and lime found in its rocks.

Closely associated with the Grenville there is an interesting eruptive rock, nepheline syenite, apparently produced by the emanations from later granites acting on the limestones. The only corundum mined in Canada occurs in such syenites at Craigmont, Ontario.

The Grenville in its greatest development forms a very thick series of rocks, reaching, according to Adams and Barlow, 17,824 feet in Burleigh and Chandos townships of eastern Ontario, and as much as 94,406 feet along the Hastings road, 50,286 feet being pure limestone. If the last estimate is correct there are few, if any, limestone formations of later ages to compare with it.

DISTRIBUTION OF THE GRENVILLE

These rocks are widely found from Lake Huron eastward in southern Ontario and Quebec, extending along the southern border of the "Canadian Shield" from Georgian bay to a point beyond St. Maurice river at Three Rivers, Quebec, their eastern boundary being somewhat uncertain. Rocks of a similar kind, probably of the same age, are found in various places toward the north-east in Labrador, especially along the southern coast and in the north-east peninsula. Crystalline limestones are largely developed also north of Hudson straits in Baffin Land. The Grenville rocks, which are well displayed in the Thousand Islands region, extend across the St. Lawrence into the Adirondack mountains of New York, covering a wide area, while similar rocks are reported from the states farther east. Dr. Adams estimates the extent over which these rocks are distributed at 83,000 square miles, and thinks that originally they may have covered the whole region.

There are crystalline limestones and sedimentary gneisses

in the wide-spread Shuswap series of British Columbia, the oldest rocks in the province, which may be Grenville in age, though at such a distance and in the absence of fossils this cannot be certainly proved.

The oldest sediments found in the Pre-cambrian of Scotland, Scandinavia, and Finland much resemble the Canadian Grenville, and rocks of the same type are known in India and in southern Brazil; so that in several continents the geological record begins with sediments, now metamorphosed into crystalline limestones with graphite, garnetiferous gneiss, and quartzite. Whether they are all of the same age, however, there is at present no means of determining.

ECONOMIC FEATURES OF THE GRENVILLE

The easily weathered Grenville limestones provide some of the best soils of south-eastern Ontario and the adjacent parts of Quebec. The limestones themselves furnish handsome marble near Bancroft and elsewhere, and they are burnt for lime when pure enough. Graphite, phlogopite or amber mica, talc, magnesite, and corundum are mined in the Grenville to an important extent; and in former years apatite (phosphate) and iron ore (magnetite) were obtained in considerable quantities from deposits connected with the Grenville series.

ATTITUDE OF THE GRENVILLE

Grenville rocks are apt to run as long bands between areas of gneiss, since they commonly form synclinal troughs caught between the batholiths of the Laurentian. These bands may run out as tongues or may change their strike and enclose oval areas of gneiss. Usually the Grenville rocks have steep dips, as might be expected under the circumstances. The originally flat-lying Grenville sediments were domed up into mountain ranges by the rise of the batholiths beneath, but these ancient mountains have usually been so far eroded as to leave only the lower parts of the Grenville syncline, protected by the more resistant gneisses on each side. Rarely, as at St. Jean de Matha in Quebec, do we find the Grenville rocks lying nearly horizontal at the top of broad low domes which have escaped complete destruction.

THE KEEWATIN SERIES

THE KEEWATIN OF THE TYPE LOCALITY

The Keewatin rocks in their typical locality on Lake-of-the-Woods are strikingly different from those of the Grenville series, consisting mostly of volcanic materials of various kinds with only subordinate sedimentary deposits, or, in some areas, none at all. The sedimentary rocks which do occur are chiefly black slates and greywacke, which have very little in common with the limestones, gneisses, and quartzites of the Grenville, though they seem to occupy about the same position in the west as the Grenville in the east. Old lavas like the western Keewatin rocks have been found conformably beneath Grenville rocks in eastern Ontario by Miller and Knight, however, confirming the conclusion that the two series are of about the same age.

The Keewatin was a time of great volcanic eruptions, which took place, at least in part, beneath the sea, as is proved by the "pillow" or "ellipsoidal" structure often observed. The majority of the lavas were very basic, such as basalts, and have since been weathered into greenstones, or have been squeezed or rolled out into green schists. In most cases the green mineral of the schists is chlorite, but near the granite contacts it may be changed to hornblende. In places there are amygdaloidal lavas, and also ash rocks or agglomerates made of volcanic bombs and lapilli.

In smaller amounts one finds rhyolites, now often transformed into pale schists, with mica in the form of sericite. In addition to the volcanic rocks there are dikes, sheets, and bosses of basic and acid rocks related in various ways to those described before, and also dikes of pegmatite and granite coming from the later Laurentian batholiths.

The sediments found in subordinate amounts include mainly greywacke and slate, the latter rock sometimes black and charged with carbon. Conglomerates, also, have been ascribed to the Keewatin, but it is probable that they really belong to the next geological period.

The only economic mineral found in the original Keewatin region is gold, which occurs in many places at or near Lake-

of-the-Woods, as well as Rainy lake, but has nowhere been mined with profit.

THE KEEWATIN SERIES IN OTHER REGIONS OF CANADA

A band of Keewatin interspersed with granite, gneiss, and later sediments extends to Thunder bay. It includes lavas, ash rocks, and schists like those just mentioned, and also extensive iron ranges, as at Hunter's island and the Mattawin river, in which banded jasper plays a large part. In this case the iron occurs as hematite or as hematite mixed with magnetite. Thus far the typical iron ranges of the region have supplied no ore, though important mines occur near Ely in Minnesota, on the Vermilion iron range, just south of Hunter's island. A large deposit of magnetite rather low in grade, and sulphurous, occurs, however, as lenses in a ridge of greenstone at Atikokan, where some mining has been done, the ore being smelted at Port Arthur.

The next important band of Keewatin appears at Michipicoten bay, on the north-east side of Lake Superior, running first eastward, then curving north, and finally running for fifty miles or more to the west. In addition to lavas, often showing typical pillow structure, there are pale-green schists with carbonates, and ridges of the iron formation of an unusual kind, in many cases including great deposits of siderite associated with pyrite. By the weathering of these materials the Helen iron ore deposit was formed, the most important thus far worked in Canada. The ore is partly limonite and partly hematite, and pyrites has been obtained from the same mine. A large deposit of siderite, which when roasted gives a fair ore, is now worked at the Magpie mine, a few miles away from the Helen mine.

Large areas of Keewatin occur north of Sudbury at Moose mountain, where an iron mine has been worked, and extend with interruptions of later eruptives and sediments of the Timiskaming series to the Porcupine region, where some valuable gold deposits are enclosed partly in these and partly in later rocks. In addition large or small areas of rocks like the Keewatin with lavas and iron formation have been found widely scattered over the Archæan to the north-east and

north-west of James bay. Probably more of them will be discovered as the regions farther north are explored.

THE KEEWATIN SERIES IN OTHER COUNTRIES

The Keewatin bands in western Ontario sometimes cross the boundary and extend into Minnesota and other neighbouring states, in some places furnishing large deposits of iron ore, but away from the Lake Superior region Keewatin rocks have not been found with certainty. It is of interest to note, however, that interbanded silica and iron ore are found in connection with the most ancient rocks of several countries, as in Brazil, South Africa, Australia, and Scandinavia. Whatever the source of these masses of silica and iron oxide, the process of forming them seems to have been wide-spread in the world in the earliest known ages, while in later times they are rare or entirely absent.

THE COUTCHICHING SERIES

When field work was carried eastward from Lake-of-the-Woods to Rainy lake it was found that sedimentary rocks occur, in some places on a large scale, beneath the Keewatin lavas and schists of the latter region. They are widely different from those of the Grenville and consist of monotonous grey gneisses and mica schists often containing garnets and staurolites. The Coutchiching represents muddy or sandy sediments.

The sedimentary and volcanic rocks of the series which have been described must have been laid down upon a floor of solid rock, the bottom of the sea in those days, but it is very surprising that no such floor has ever been discovered. It seems to have been destroyed and worked over into other forms during the tremendous changes that followed.

THE LAURENTIAN

In every known region of the Keewatin and Grenville the rock beneath consists of gneiss or granite which has welled up in a molten state, forming batholiths and doming up the over-

lying lavas and sediments, whose remnants remain as synclinal meshes or tongues between the greatly eroded masses of gneiss. Strictly speaking, eruptive rocks should be looked on as in a sense accidental, and not to be included in the divisions of a time scale; but the building of batholithic mountains over the immense area shown in our Archæan region marks an event of great importance in the geological history of the country, and probably demanded a vast length of time. It seems desirable, then, to take up the Laurentian as marking a long-continued and most significant series of operations profoundly affecting Canadian conditions for all later time and forming the substratum of the great Canadian Shield, about which the continent has been built up, largely of materials derived from the Laurentian mountains.

The rocks of the Laurentian have mainly the composition of granite, granodiorite, or syenite, with smaller amounts of gabbro or diorite; but usually these materials have a schistose or banded structure and are termed gneiss. The rocks are mostly coarse-grained and often contain porphyritic feldspar crystals, and, in many cases, they have been sheared into "porphyritic granitoid gneiss," a very common phase of the Laurentian.

Laurentian batholiths are often oval, but sometimes irregular in shape where several upwellings have combined, and have a schistose structure parallel to the curving edge, changing inwards to the ordinary structure of granite. They may be of all sizes, from a few miles to fifty miles in longest diameter, as on Rainy lake; and their general arrangement runs roughly north-east (50°-80° east of north), indicating the direction of the great mountain chains of which they formed the cores. The steeply dipping schists surrounding many of the larger batholiths outline the foundations of ranges which may have been higher than the present Rockies.

Cutting all the rocks mentioned there are dikes of coarse pegmatite, the last of the granitic materials to crystallise, often with giant crystals of feldspar and other minerals. Two large dikes have been worked in eastern Ontario as mines of potash feldspar, supplying thousands of tons for the use of potteries. In a general way, however, the Laurentian is very barren of valuable products except in a few places where

granite is quarried for paving or other purposes. As mapped on the Canadian Shield the Laurentian covers an enormous space, probably more than 1,000,000 square miles, though there is reason to believe that similar batholithic upheavals took place at a later age. As the rocks of the two ages are much alike, the two sets of granites and gneisses have been separated only in a few areas which have been mapped in detail.

OTHER REGIONS WHICH MAY BE LAURENTIAN

There are other large areas which have the character of the Laurentian and underlie unconformably all formations except the very oldest in the Selkirk and Gold Range mountains of British Columbia, and smaller ones in Nova Scotia and New Brunswick. Outside of Canada the Laurentian extends south at the Thousand islands and forms a large part of the Adirondack mountains, and similar ancient granites and gneisses occur in the Appalachians and in other regions of the United States. Rocks of the Laurentian type exist in Greenland, and cover a large part of the Scandinavian Shield in Norway, Sweden, and Finland, and a smaller tract in the Highlands of Scotland. It is probable that these regions were once directly connected with the Canadian area.

All the great subdivisions of the world include areas of granite and gneiss at the base of the geological succession, occupying apparently the same position as our Laurentian, and similar rocks have been found in drill holes beneath hundreds and even thousands of feet of later rocks. They occur, for instance, at 1100 or 1200 feet beneath the city of Toronto. It seems probable that they everywhere underlie the oldest sedimentary rocks and, therefore, form the universal basement for the later geological formations.

THE POST-LAURENTIAN INTERVAL

Before the next series of sedimentary rocks was laid down there must have been a tremendous interval to permit of the destruction of the great mountain ranges of the Canadian Shield. This seems to have been a dry land period when the

weather, running water, perhaps also frost or ice, did effective work, for the overlying materials, Grenville or Keewatin, of the batholithic mountains seem to have been largely destroyed and the granite cores deeply eaten into. What became of the materials we do not always know, but in any case the basal rocks of the next great period of known geological time consist of debris that must have come from this destruction. How long the interval of erosion lasted there is no way of estimating, but it must have meant millions of years.

THE SUDBURY OR TIMISKAMING SERIES

On the erosion surface of the ancient mountain area a great succession of sediments—conglomerates, sandstones, greywackes, and shales—was laid down, now metamorphosed into schist conglomerate, quartzite, slate, or schist, etc. The thickest known development of the series is in the Sudbury region, which has been more carefully studied than the others and may be considered typical.

Conglomerate is not extensively found in this series near Sudbury, but when it occurs it consists of well-rounded pebbles and stones of various kinds with a cement like greywacke. The lowest rock of the series is the *Copper Cliff arkose*, often so much recrystallised as to resemble syenite or felsite. It was formed under conditions which allowed granites or gneisses to crumble without much decay of the feldspars, so that the climate was probably either desert-like or cool and moist, the latter being more likely.

Then follows greywacke with thin slaty layers very uniformly stratified with coarser and finer bands, perhaps representing the change of seasons, and finally quartzite in thick beds, sometimes showing cross bedding. The whole series has been tilted, often at an angle of 45° or more, and the total thickness is not less than 20,000 feet.

Towards the end of Sudburian time there were eruptions of very basic lava, showing pillow forms and also amygdaloids. All of the rocks mentioned are older than the adjoining granites and gneisses, which often contain fragments of the sediments, and penetrate them in elaborate ways. In such

cases the sedimentary rocks are more or less metamorphosed into schists or even into gneiss.

The Sudbury rocks just described seem to be of the same age as the *Timiskaming* series to the north and east, near Lake Timiskaming, and at the gold mines of Porcupine. Except that there is more conglomerate, the rocks are alike in almost every respect, and they have been cut by granites as at Sudbury.

The *Pontiac* series in Quebec has similar relations, and this is true also of the *Doré conglomerate* on Michipicoten bay.

FIG. 73. TIMISKAMING SERIES, PORCUPINE, ONTARIO

Here there are schistose conglomerates several thousands of feet thick, enclosing boulders of a great variety of rocks, such as granite, greenstone, and iron formation, sometimes reaching diameters of two or three feet. This conglomerate is possibly of glacial origin, but the stones enclosed in it are too much squeezed and rolled out to give the final evidence of ice action.

Much farther to the west, between Thunder bay and Lake-of-the-Woods, a great series of sedimentary schists and conglomerates, called by Lawson the *Seine* series, reminds one very much of the Sudburian. It too is upheaved and cut by later granites which have often greatly metamorphosed the sedimentary rocks.

If all of these areas belong to the same period, which is

probable, the Sudbury and related series represent a thick and wide-spread group of coarse sediments, probably laid down in shallow seas after the original land surface had sunk beneath the waters, perhaps formed as delta materials near the mouths of great rivers.

The *Hastings* series in eastern Ontario, sometimes considered a less metamorphosed part of the Grenville, is believed by Miller and Knight to be the equivalent of the Timiskaming series, since a conglomerate at its base includes pebbles derived from the Grenville. The Hastings series contains limestones, which are infrequent in the Sudbury and Timiskaming series.

Rocks of the age just described have not yet been recognised in other parts of America or in other continents.

GENERAL FEATURES OF THE EARLIER PRE-CAMBRIAN

All the series of rocks thus far mentioned, both sedimentary and eruptive, have undergone great changes since they were first formed, and are now so metamorphosed by mountain-building activities, folding, faulting, shearing, and penetration by later eruptives, that their original character is often hard to determine. The older series, such as the Grenville and Keewatin, have of course suffered more than the Sudburian, but all have been more greatly changed than the later Pre-cambrian, which remains to be described.

In spite of this blurring of the record there is reason to believe that the condition of the world was not greatly different from that of later ages. The world was not intensely warm, as old theories suggested, for water was at work during the whole time. There were mountain-building thrusts, great volcanic eruptions, and also the slow wearing down of the mountains, but the same type of work has been going on ever since, and so far as geologists know, with much the same intensity. Except as to life, of which we know nothing positively, it is surprising to find our earliest glimpses of the earth so like conditions which reach even to the present.

THE ALGOMAN OR POST-SUDBURIAN GRANITES

Granites and gneisses seem everywhere to have invaded and tilted or folded or domed up the sedimentary rocks just described, very much as the Laurentian eruptives acted upon the Grenville and Keewatin. It is, in fact, often very difficult to distinguish the two sets of deep-seated eruptives, each of which seems to have formed batholithic mountains. Dr. Lawson has given these later granites and gneisses the name of *Algoman.* Up to the present there are only a few localities where they have been separated from what was formerly called Laurentian. The Algoman granites and the dikes sent off from them are credited with supplying the gold of most of the mines in northern Ontario, especially those of Porcupine, which include one of the greatest gold-mines in the world, the Hollinger mine, as well as several other important deposits.

THE POST-ALGOMAN INTERVAL

Following the Algoman eruptions of granite came a great period of erosion when at least the southern part of the Canadian Shield was dry land, and was slowly attacked by the epigene forces and ultimately was reduced to a peneplain with a surface of gently rounded hills and shallow valleys. It appears as if this process of levelling was so thorough that all later weathering and destruction of the surface during dry land conditions have not greatly changed the character of the country.

THE HURONIAN SERIES

After what appears to have been the longest break in the Pre-cambrian history of Canada, the Huronian begins as coarse sedimentary rocks formed at or near the southern edge of the shield, with the greatest development in the typical locality on the north shore of Lake Huron. These rocks were mapped on a small scale more than sixty years ago by Logan's assistant, Murray; but the country was covered by forests

and difficult to traverse except by canoe routes, so that his work was more or less imperfect. Recent work by Collins of the Geological Survey shows that the Huronian really consists of two divisions separated by an important discordance, the lowest being named the *Bruce* series and the upper the *Cobalt* series.

The Bruce series begins with 1000 to 2000 feet of white quartzite, often conglomeratic at the base, followed by thinner formations of conglomerate, limestone, and greywacke; it ends with 1000 feet of white quartzite and 40 feet of greywacke, the whole series having a thickness of 3000 feet or

FIG. 74. STRIATED STONE FROM COBALT TILLITE

more. Most of the beds are water laid, though there are hints of dry land conditions in some deposits.

After a somewhat important break implying a good deal of erosion of the Bruce series, the Cobalt series commences with a boulder conglomerate which is really a tillite or ancient boulder clay. This is, of course, a continental formation made under arctic conditions and implies an important glacial period, the earliest certainly proved in the history of the world. This basal conglomerate or tillite has furnished good

specimens of striated stones at Cobalt and two other places; and its great boulders, often far from their source, with other features closely like the effects of ice in other ages, support this evidence.

The tillite is followed by 600 or 800 feet of white quartzite, nearly 3000 feet of "slate conglomerate," and thousands of feet of red or white quartzite, including the showy jasper conglomerate with red pebbles in a white ground. Then come 200 feet of cherty limestone and 400 feet of white

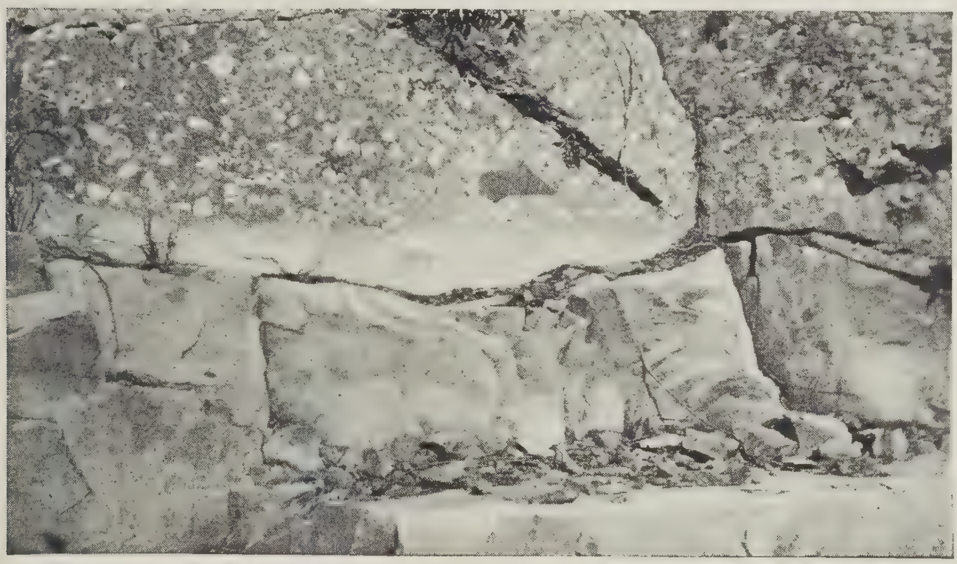

FIG. 75. TILLITE (BOULDER CONGLOMERATE) OF COBALT SERIES RESTING ON KEEWATIN GREENSTONE, COBALT, ONTARIO

quartzite, the whole series measuring probably more than 12,000 feet in the region north of Lake Huron.

The basal tillite of the Cobalt series, or Upper Huronian, has been followed from the typical Huronian region to Cobalt, and is believed to occur at Chibougamau and at other points in the north and north-east, so that it seems to be much more widely spread than the Bruce series, which has not been found with certainty away from the typical Huronian region.

Among the Huronian rocks the limestone often looks comparatively modern and suggests animal life, though no fossils have yet been found in it, unless the limestone of Steeprock lake in the Seine River region far to the west is considered to be of this age. In the Steeprock limestone two

or three species of *Atikokania* occur, an organism supposed to be related to the sponges or to the somewhat problematic *Archæocyathinæ* of the Cambrian. These are large fossils and do not suggest the earliest beginnings of life. Black carbonaceous slate occurs in a thin bed at Cobalt, suggesting, perhaps, plant life as the source of carbon.

Huronian rocks extend south of Lakes Huron and Superior into Michigan, Wisconsin, and Minnesota, and are of importance as containing iron ores. Formations considered Huronian are found also in Newfoundland, and one or two obscure fossil forms have been reported from them. Whether the "Beltian" rocks of the west are Huronian or not is uncertain. They will be mentioned later. Pre-cambrian sediments not greatly metamorphosed occur in various parts of the world and may be of Huronian age, but a certain correlation is impossible at such great distances in the absence of fossils.

THE ANIMIKIE SERIES

The Animikie begins, it is believed, with a great transgression of the sea over the Canadian Shield. Rocks of this age were first described from the Thunder Bay region, where they have a thickness of 1500 or 2000 feet and rise as cliffs of chert and slate with one or more great sheets or sills of diabase, forming the flat-topped hills so characteristic of the north-east side of the Lake Superior coast. Farther southeast sandstone or quartzite shows beneath these rocks, and at some points there is a little impure iron ore. A thin conglomerate underlies the formation at a few points on Thunder bay, resting on the upturned edges of the Keewatin and Laurentian schists and gneisses. Silver has been mined at several places in these rocks and the dikes that intersect them, the mine on Silver islet being worked in the richest deposit.

The continuation of the Animikie into Minnesota supplies the great iron deposits of the Mesabi, perhaps the most important in the world.

The thickest group of rocks ascribed to the Animikie is the *Whitewater* series enclosed as a basin within the nickel-bearing eruptive of Sudbury. This consists of a boulder conglomerate,

followed by tuff, black slate, and sandstone, the whole reaching a thickness of 9450 feet. The slate is rich in carbon, like the black slate at Kakabeka falls near Fort William; and veins of anthraxolite, much like anthracite in appearance and composition, are found in both places. The shale was probably once bituminous, suggesting life at the time, and anthraxolite was pitch which has since lost its volatile constituents. This material has several times roused false hopes of coal mines.

Several other regions in northern Canada display rocks like the Animikie, but usually associated with volcanics and sandstones belonging to the next age. They are found along the east shore of Hudson bay, in the northern part of Labrador, and near Great Bear lake, and in many places include iron ores of a low grade.

The rocks of the Animikie, when not modified by later sheets of diabase, look very modern, so that fossils might be expected, though none have been found with certainty. They often lie nearly flat and are seldom folded except in the interior of the Sudbury nickel basin, where collapse has caused compression, forming a number of narrow anticlines. Often, however, these beds have been faulted and the blocks gently tilted, as near Port Arthur and Fort William.

The Animikie has not been reported from other countries except in the states to the south and west of Lake Superior, in the iron region.

THE KEWEENAWAN SERIES

After a considerable break the Keweenawan follows the Animikie, but without much angular discordance. This appears to have been a time of emergence of the land, often with immense outpourings of lava, probably equalling in this respect the Keewatin. A basal conglomerate, sometimes bouldery, may rest upon the Animikie, as near Thunder bay, or else upon the Laurentian or the Keewatin; and this is followed by white and red sandstones, limestones, and shaly rocks, the whole having a thickness of 1300 or 1400 feet near Thunder bay. The rocks show cross bedding and mud cracks, the feldspars in some of the sandstones are little weathered,

and red colours are common—all features suggesting continental and probably desert conditions.

The sedimentary rocks just mentioned are cut by many dikes and are interbedded with sills of diabase, and resting upon them at various places on the north and north-east shores of Lake Superior there are thousands of feet of lavas. These are mainly basic, the equivalents of the modern basalts, but there are also quartz and feldspar porphyries and felsites, representing the modern rhyolites. Along with the lava flows there are conglomerates and sandstones in comparatively small amounts, formed of contemporary volcanic materials such as the porphyries.

The lavas are often highly amygdaloidal and with uneven slaggy surfaces, but show no pillow structure. The amygdaloids contain a variety of minerals, including agates, thompsonites, etc., which make pretty ornamental stones; and also native copper in small amounts.

While copper has not been mined profitably on the Canadian side of Lake Superior, some of the most important copper mines in the United States have been worked on Keweenaw point in Michigan.

The volcanic series has a thickness of 11,230 feet on Michipicoten island and of 16,208 feet at Mamainse near the east end of the lake, but is twice or three times as thick in Michigan.

The Lake Superior Keweenawan has been more thoroughly studied than that of any other area, but red sandstones and conglomerates, generally with lavas which are often copper-bearing, occur near Lake Athabasca and Great Slave lake, and cover a very large area east of Great Bear lake and near the suggestively-named Coppermine river on the Arctic coast of Canada, whence the Eskimos in early days obtained native copper for tools and weapons.

While the Keweenawan lavas have not yet furnished much copper in Canada, it is believed that eruptive rocks of the same age and origin have been of great importance in providing the ores of several mining regions of northern Ontario. This is probably true of the great boat-shaped sill of norite and micropegmatite with which all the Sudbury nickel-copper ores are associated, and also of the diabase sheet with which the rich silver veins of Cobalt are connected.

Undoubted Keweenawan rocks are not known beyond the Canadian Shield except in the states bordering on Lake Superior. Sandstones and conglomerates, probably of desert origin, called the *Torridonian*, occur as the latest Pre-cambrian in the highlands of Scotland, and similar rocks are found in other continents as well as Europe.

THE WESTERN PRE-CAMBRIAN

Beside the vast area of Pre-cambrian of the Canadian Shield, not far from 2,000,000 square miles in area, there is another Pre-cambrian region, narrow and long, extending from south-east to north-west as the central axis of the Cordilleran mountain chains, making up most of the Purcell, Selkirk, and Gold ranges of British Columbia. This area has been studied in much less detail than parts of the Pre-cambrian of Ontario and Quebec, and the age relations are much less certain; so that it seems wiser to take up these formations separately instead of attempting to include them under the subdivisions known in eastern Canada. Two subdivisions are generally recognised: a lower one, called the *Shuswap* series, which has been intruded by batholiths of granite or diorite; and an upper one, commonly called the *Beltian*, from a thick series found in the states to the south and referred to the Algonkian by most American geologists.

THE SHUSWAP SERIES

The Shuswap series was so named by Dr. Dawson, who thought it equivalent to the Laurentian or Grenville of eastern Canada. It includes various schists, sedimentary gneisses, quartzite, and crystalline limestone, much metamorphosed by the granites and other eruptives which penetrate them, or perhaps by the depth to which they were formerly buried, causing regional metamorphism. Professor Daly thinks the latter is the true cause. These rocks rather closely resemble the eastern Grenville, and sometimes contain graphite. Daly puts their thickness at 29,900 feet. The granites and eruptive gneisses which penetrate them have the look of Laurentian rocks.

THE BELTIAN SERIES

The Beltian rests unconformably on the Shuswap series and consists of sediments which have been much less metamorphosed. Dawson and Daly divide them into a lower part, the *Nisconlith* series, and an upper part, the *Selkirk* series. The Nisconlith is made up of quartzites, slates, and limestone, the last rock in small amounts. The Selkirk series includes similar rocks, but less metamorphosed. The total thickness of the Beltian section is given at 32,752 feet. Most of these rocks seem to have been laid down under water, but there are many instances of beds containing ripple marks, mud cracks, and casts of salt crystals, implying shallow water or dry land conditions, perhaps even a desert climate.

It is probable that the Beltian rocks were laid down in a great geosyncline, running about north-west and south-east, and sinking gradually as the beds were deposited.

Although many of the Beltian rocks of British Columbia are little changed and closely like the overlying Cambrian, no fossils have been found in them. Very similar sedimentary rocks in Montana, to the south, have been found by Walcott to contain a few fossils, the best known being an arthropod named *Beltina*, an animal fairly high up in the scale of life in spite of the fact that it occurs 7000 feet below the base of the Cambrian. Why fossils should be so very rare in these sediments is one of the puzzles of historical geology.

Rocks like the Beltian occur for a long distance south of the boundary and are found in the Grand Canyon of the Colorado in Arizona.

It is probable that the Beltian beds were deposited later than the Sudbury or Timiskaming series, since they have not been invaded by batholithic areas of granite and gneiss: but whether they correspond to the Huronian, the Animikie, or the Keweenawan, or perhaps to more than one of these divisions, there is no means of deciding.

CONDITIONS IN THE LATER PRE-CAMBRIAN

Except near the southern edge of the Canadian Shield, the rocks of the Huronian and later series are generally little changed and their record is easily read. The boulder clay or

tillite of the Cobalt series is as typical and well preserved as that of the Permo-Carboniferous, which came millions of years later, and is just as suggestive of chill ice fields and wintry blizzards as the Pleistocene boulder clay of Ontario in a period just before the present. There are, too, in the Keweenawan clear proofs of desert heat and drought with sand storms and withering winds as in the Sahara; but most of the sediments show moderate conditions, flowing rivers, waves that left ripple marks, the effects of weathering, all like the familiar surroundings of the present, with perhaps a more wide-spread volcanic activity in Canada during the Keweenawan than at any later time.

Our knowledge of the life of the Pre-cambrian world, however, is still most meagre. Not a dozen species of plants or animals are known from the many thousands of feet of sediments laid down on sea bottoms just like the present. There is nothing to justify a prophecy that the shallow waters would swarm with living beings in the next period of geological time.

CHAPTER V

THE PALÆOZOIC ERA—THE CAMBRIAN PERIOD

The Pre-cambrian era is followed by another long era to which the name *Palæozoic* is given, on account of the ancient character of all the life of the time. Between the beginning and the close of the Palæozoic vast physical changes took place, and extensive development occurred in the animal and vegetable worlds. The duration of the Palæozoic was so long and the physical and faunal changes so great that the era is easily divided into a number of periods. It is proposed to consider first these periods one by one, in order that the student may become acquainted with the march of events before discussing the Palæozoic as a whole; a summary of Palæozoic history is deferred, therefore, until after the various periods have been studied.

The lowest division of the Palæozoic group of rocks is known as the *Cambrian system,* and the same term is applied to the time during which these rocks were deposited—the *Cambrian period.* The name is derived from "Cambria," the Roman name for the northern part of Wales.

Time is continuous; we can conceive of no breaks in the continuity of time. Similarly there is every reason to believe that sedimentation and the consequent production of stratified rocks has likewise been continuous from the inception of geological time to the present. It is well for the student to understand clearly at this point that the Cambrian is separated from the Pre-cambrian, not by the failure of geological processes to make a record of the interval, but by the failure of man to find that record. It is true, nevertheless, that nearly everywhere where Cambrian rocks are found they rest unconformably on the Pre-cambrian, indicating an interval of time which is one of the most marked in all geological history. Even this pronounced break in our earth's history is being bridged by advancing knowledge, for the Lower Cambrian rocks of southern British Columbia rest with scarcely a perceptible disconformity on the earlier Pre-cambrian strata.

PHYSICAL EVENTS IN NORTH AMERICA DURING THE CAMBRIAN

Very little is known as to the size and shape of the North American continent at the beginning of Cambrian time, but it was probably larger than at present, and certainly of very different shape. We have every reason to believe, however, that the Cambrian began, as far as certain and visible record is concerned, during a downward folding of the continent and a consequent invasion of the sea along a comparatively narrow axis extending from California northward through eastern British Columbia to the Arctic ocean. This depression is called the *Cordilleran trough.*

Simultaneously, or perhaps a little later, a similar narrow depression developed from the Gulf of Mexico to the maritime provinces of Canada (*Appalachian trough*). Most of the time during which the continental seas maintained this lineal arrangement is known as Lower Cambrian. American geologists refer to it as *Waucobian,* but the student must remember that the two terms are synonymous for North America only. The geologists of the world have not adopted the name Waucobian to replace the older term, Lower Cambrian, in its world-wide application.

The subsidence of the continent, foreshadowed by the formation of the two troughs in the Lower Cambrian, was continued in Middle Cambrian time, and the waters of the Pacific ocean were permitted to extend beyond the limits of the Cordilleran trough and to cover a large part of the continent south and west of the Great Lakes. At the same time the Atlantic waters advanced into narrow troughs in the Acadian region. The strong development of Middle Cambrian strata in the maritime provinces has led to the adoption of the name *Acadian* for the Middle Cambrian of North America.

A more or less complete withdrawal of the sea marks the close of Middle Cambrian time, but a submergence of still greater extent followed and resulted in the oceanic waters covering about 31 per cent. of the present area of the continent. The term *Croixian* is applied by American geologists

to the Upper Cambrian epoch because rocks of this age are well developed on the St. Croix river in Wisconsin.

Maps may be drawn to show the distribution of land and water at any time in the past. Such maps are known as *palæogeographic*, and are not to be confused with geological maps, which indicate the geographical extent of the various

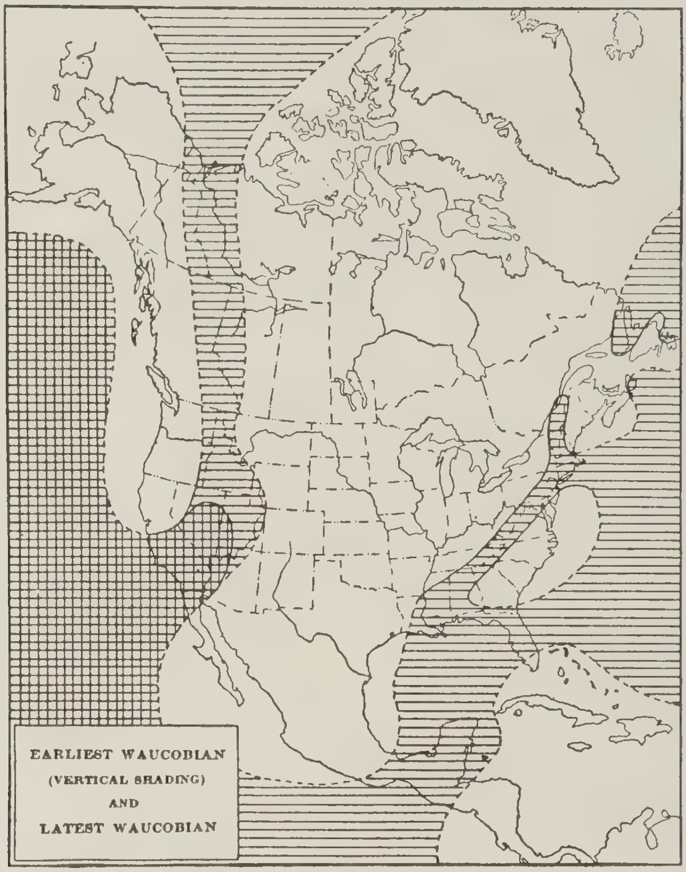

FIG. 76. PALÆOGEOGRAPHIC MAP OF NORTH AMERICA IN LOWER CAMBRIAN TIME

The white areas are land; the vertically lined areas were covered by the sea in the earliest Lower Cambrian; the horizontally lined areas were covered by the sea in the later Lower Cambrian time. *From Pirrson and Schuchert, "Textbook of Geology."*

formations. Geological maps are drawn from ascertained facts: palæogeographic maps are constructed upon data of many kinds—the known extent of the rocks, their position, their physical characteristics, the variations in fauna indicating migrations of animals and plants, and many other considerations.

The chief value of palæogeography to the beginner is that

a general conception of the distribution of land and water at a given time enables him to deduce the present position of the strata deposited during that time. It may be generally stated that sediments are always accumulating in off-shore seas. Consequently, knowing the shore line during a given time, we may safely conclude that deposits of that age were formed in the adjoining sea. It does not necessarily follow that we shall always find them in that locality now, as they may have been covered by subsequent strata or removed by erosion. It does follow, however, that rocks of a given age can be found only where comparatively shallow seas existed at the time in question.

Applying these general principles to the Cambrian rocks of North America, we find an explanation of the great gap between the Pre-cambrian and the Cambrian in the fact that the off-shore position was farther out to sea than at present. The continent has not yet been sufficiently elevated to bring into view the rocks formed during this time. As we are unable, therefore, to decipher the history of this period, we have fallen into the habit of calling it an "interval." Such intervals, numerous in the course of geological history, are merely unread passages in the unfolding tale of the earth: they do not represent breaks in the continuity of sedimentation. The whole history has been written, leaf by leaf, in the book of the rocks; unfortunately, up to the present, many of the leaves have not been found, and, more unfortunately, many of them probably will never be found.

It is significant, also, that it is the existence of these gaps that enables us to divide the history of the earth into eras and periods. To a certain extent, therefore, our geological subdivisions are founded on a lack of knowledge; but this thought must not be carried too far, as the unread intervals correspond to great physical events in the history of the earth.

THE CAMBRIAN SYSTEM IN CANADA

We have seen that at the close of Keewatin time the eastern part of Canada was thrown into great folds with a general north-east trend; these folds have persisted to the present

day. In the Lower Cambrian, and more particularly in the Middle Cambrian, the waters of the Atlantic ocean invaded the troughs between these folds; in consequence, we find narrow belts of Cambrian rocks running in a general north-east direction in Newfoundland, Cape Breton, Nova Scotia, southern New Brunswick, and the Gaspé Peninsula of Quebec. The rocks are mostly argillaceous sandstones and shales with very little admixture of limestone.

The wide-spread continental seas of the Upper Cambrian, in their latest and most extreme phase, lapped the shores of the old Pre-cambrian continent from Brockville to the

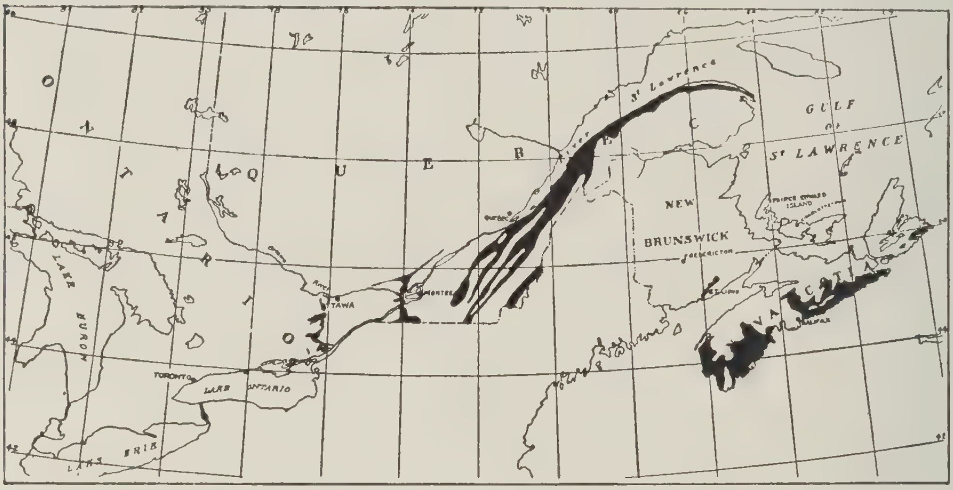

FIG. 77. SKETCH MAP OF EASTERN CANADA SHOWING THE CHIEF AREAS OF CAMBRIAN ROCKS

The areas in eastern Quebec may be, in part, Lower Ordovician, and the areas along the Atlantic coast of Nova Scotia are very uncertain as to age.

vicinity of Ottawa and easterly along the base of the Laurentide mountains. The waves found plenty of prey in the decayed surface of the old continent for the creation of a fringe of sandstone along the shore and in the shallow off-shore waters. This sandstone, known as the *Potsdam formation,* is now to be seen along the old shore as indicated above, and in somewhat wider areas in the extreme western part of the province of Quebec. The rock is usually a white or variegated sandstone, composed almost entirely of quartz grains. While generally too hard for fine carving, the stone is adapted to building purposes and has been quarried extensively at Smiths Falls, Perth, and in the township of Nepean in Ontario, also at Beauharnois and other places in Quebec.

We have seen that the Pre-cambrian rocks have a very slight width where they cross the St. Lawrence river at the Thousand islands. The exposures of Potsdam sandstone mentioned above are east of the old axis. It is to be expected that a similar fringe of sandstone would mark the shore of the old Upper Cambrian sea on the west side also. Doubtless such a fringe was formed, but its exact location is not ascertainable as it has been buried under later rocks formed in later seas which advanced farther on the continental axis. This is a good example of the obliteration of a record by burial. Nevertheless there is proof of the existence of this sandstone, as a few small exposures are known at Kingston Mills and in the township of Loughborough. Also its presence has been revealed by boring through the overlying rocks at points farther west.

Following the contact of the Pre-cambrian with later rocks north and west from the vicinity of Kingston to the Arctic ocean, we find no more Cambrian rock except near Sault Ste. Marie. A variegated sandstone, probably of Upper Cambrian age, forms the "pictured rocks" in Michigan to the west of the outlet of Lake Superior and crosses the St. Mary river into Canada at Sault Ste. Marie.

The grandest exposures of Cambrian rocks are found along the inner ranges of the Rocky mountains. We have seen that in early Cambrian time a local sinking of the continent permitted the sea to invade this region. The original narrow depression, the Cordilleran trough, continued through long geological periods to mark the axis of an area of progressive submergence. The sediments accumulating in this trough were gradually bent downward, resulting in the production of one of the great structural elements of the continent—the Rocky Mountain geosyncline. Sediments of Lower, Middle, and Upper Cambrian time accumulated in this depression to a thickness of 12,200 feet at Mount Robson near the line of the Grand Trunk Pacific Railway, and in the southern part of the province of British Columbia to the enormous thickness of more than 18,500 feet. Many of the grandest peaks of the Canadian Rockies are composed of Cambrian rocks. The stupendous changes whereby these sea-made rocks have been raised to their present lofty position occurred at a much later

date, and constitute one of the most fascinating chapters in geological history.

The Cambrian rocks of the mountains were originally sandstones and shales towards the bottom, with more limestone at the top. The severe metamorphism which the strata have undergone has altered the sandstone into quartzite and the shale into slate; the limestones have been converted, in part at least, into marble. The cracking and deformation which these rocks have suffered in the process of mountain-making have rendered them unfit for structural purposes. Attempts

FIG. 78. LAKE LOUISE, ROCKY MOUNTAINS

have been made to use the slates for roofing without great success. Lake Louise, one of the beauty spots of the world, nestles among towering peaks of Cambrian rocks.

THE LIFE OF THE CAMBRIAN

The Proterozoic contains some meagre evidence of the existence of life, but the fossils are so extremely rare and so poorly preserved that they are of little or no assistance in working out the geological record. With Cambrian time, however, life developed to an extent that fills us with astonishment at its complexity and the apparent abruptness of its appearance.

It is a most significant fact that all the branches of invertebrate animals had their inception in or before the Cambrian period. Assuming that all life developed from one original source, we are forced to conclude either that a very long time intervened between the Pre-cambrian and the Cambrian or that life existed in the Pre-cambrian to an extent very much in excess of the evidence that has yet been found.

We can scarcely conceive of the numerous animals of the Cambrian having existed without plants for food; nevertheless, the actual evidence of vegetable life is very meagre. Certain markings and impressions are thought to represent seaweeds, and in all probability do, but certain evidence of plant tissue has yet to be found.

While we are impressed by the high development of the Cambrian invertebrates, two points must be carefully noted: first, that the total amount of life is very meagre, both in the number of species and in the actual number of individuals, compared with the great faunas of succeeding geological ages; second, despite the high degree of development attained, the organisms are the most primitive examples known of the classes to which they belong.

Although it is important to recognise the unexpectedly high development of Cambrian life on account of its bearing on the evolution of organisms, we may eliminate most of the classes in an account of the dominant life of the time. Most of the groups are so feebly represented that they require no further mention. The great majority of Cambrian fossils are either trilobites or brachiopods; the two crustacean super-orders, ostracods and phyllopods, are also of importance.

Trilobites. These animals are crustaceans—*i.e.* they are allied to lobsters and crabs, and therefore are to be ranked high among invertebrate creatures. Trilobites are primitive crustaceans, however, and differ from all other members of the class in possessing a longitudinal furrowing of the shell into three lobes—whence the name *tri-lobite*. The dorsal surface is covered by a thin investment which is divided transversely into three portions—an anterior part, the head or cephalon; a central part, the body or thorax; and a posterior part, the tail or pygidium. The cephalon is

composed of three pieces—a central part, and two lateral pieces known as free cheeks. The line of suture between the parts is called the facial suture, and is of the first importance in classifying trilobites.

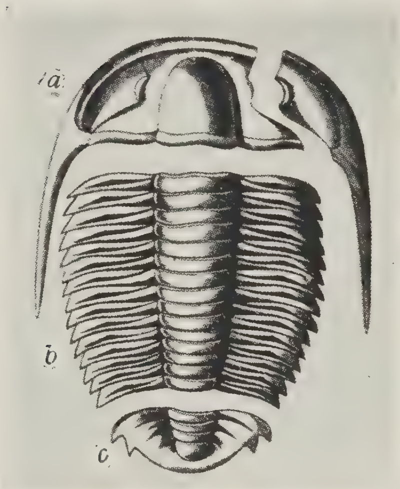

FIG. 79. A TRILOBITE DISSECTED TO SHOW CHIEF POINTS OF THE ANATOMY

(*a*) The head or buckler, consisting of the central part (cranidium) and two fixed cheeks; (*b*) The thorax, consisting of a variable number of separate "rings"; (*c*) The tail or pygidium in a single piece. Note the longitudinal trilobation of the whole animal.

The thorax is composed of narrow transverse pieces called thoracic rings: the number of these varies greatly in different genera and is of importance in classification.

The pygidium is a single piece, but it shows evidence of having arisen by the fusion of a number of original segments.

The under side was protected by a very delicate investment carrying one pair of appendages to each original segment—five for the head, one for each thoracic ring, and one for each of the original segments of the tail.

Three types of trilobites are recognised according to the position of the facial suture—a low type in which there is no suture on the upper surface, an intermediate type in which

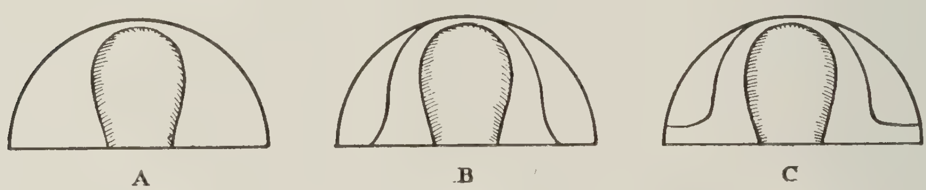

FIG. 80. DIAGRAMS OF THE HEADS OF THE THREE TYPES OF TRILOBITES

(A) Simplest type with no free cheek; (B) Intermediate type with the free cheek including the posterior angle of head; (C) Highest type in which the free cheek does not include the posterior angle of the head.

the suture terminates at the back of the head, and a high type in which it comes out at the side of the head.

Trilobites are characteristic of the whole of the Palæozoic era, and were the dominant organisms of the Cambrian period. The Cambrian trilobites belong to the first two types only; the higher forms had not yet appeared.

Fifty-five genera and more than 300 species of Cambrian trilobites are known: their great diversity is shown by the remarkable variation in size, from the little *Agnostus*, one-fourth of an inch long with only two thoracic rings, to the giant *Paradoxides*, ranging up to eighteen inches in length with as many as twenty thoracic rings. The three divisions of Cambrian time are so clearly marked by different types of trilobites that the Lower Cambrian is known as the *Olenellus* zone, the Middle as the *Paradoxides* zone, and the Upper as the *Olenus* zone.

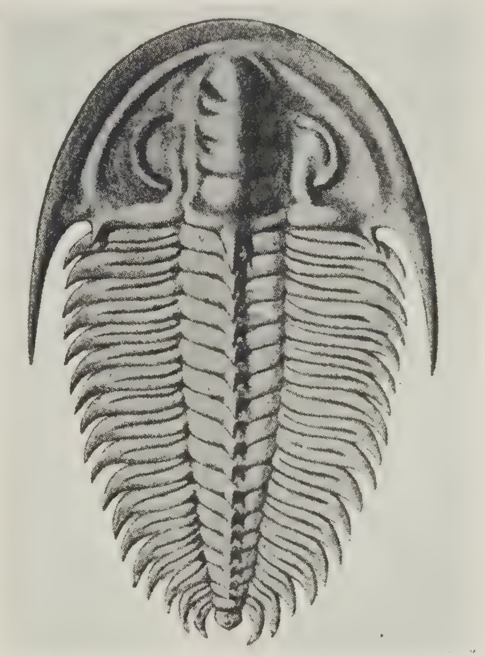

FIG. 81. OLENELLUS, THE TYPICAL TRILOBITE OF THE LOWER CAMBRIAN

From a restoration by Lapworth.

BRACHIOPODS. In the Cambrian these creatures rank in importance next to the trilobites; they survive throughout all succeeding ages and exist in the seas of the present day.

The shell of a brachiopod consists of two halves or valves which are not alike as in the case of the common clam. On the other hand, a line drawn from the beak to the front margin of the shell divides both valves into similar halves; in this respect, also, the shell of a brachiopod differs from that of a clam. Brachiopods live with the beak of the shell downward, and are attached to the floor of the sea by a fleshy structure, the peduncle, which generally comes out between the two shells. It is customary to draw figures of brachiopods in the reversed position, *i.e.* with the beak up.

In the simplest forms the two valves are not connected by a definite hinge, and the peduncle emerges freely; in higher forms the valves are hinged and fit closely together, necessitating a special opening for the peduncle. Modifications of this passage, of increasing complexity, occur with the

advance of geological time; as these changes are in accord both with the march of time and the evolution of the race, they are used as the main basis for the classification of brachiopods.

The soft body of the brachiopod lies between the two valves, to which it is attached by two thin sheets of tissue,

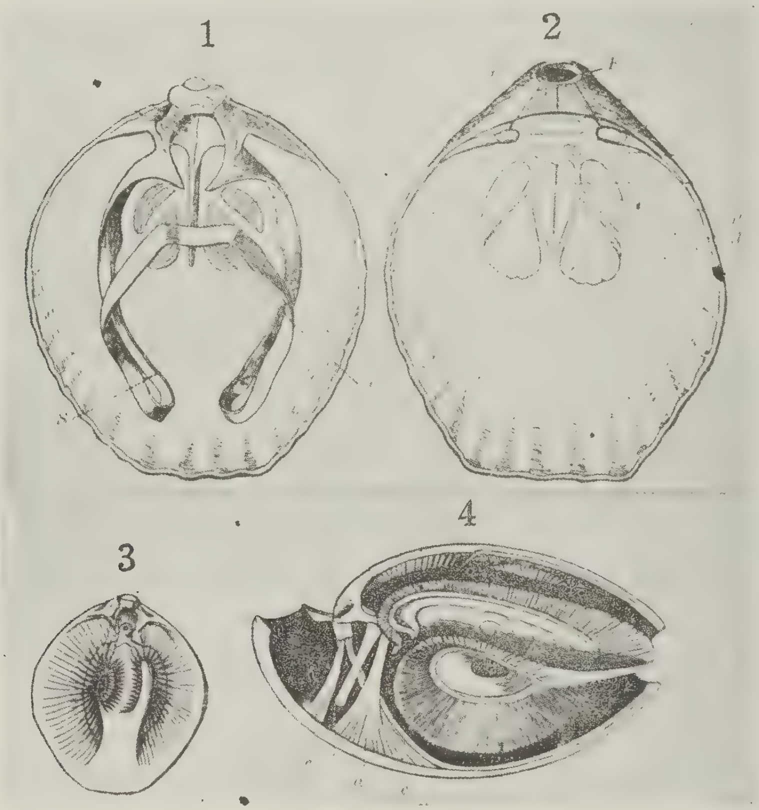

FIG. 82. STRUCTURE OF THE RECENT BRACHIOPOD, MEGALLANIA FLAVESCENS

1. Interior of the brachial valve showing the loop (S) and muscle scars (a); 2. Interior of the pedicle valve showing the muscle scars (p, d), the opening for the passage of the peduncle (F), and the deltidial plates (D); 3. Another species showing the fleshy breathing arms; 4. Vertical section through both valves showing the closing muscles (a), the opening muscles (c), and the breathing arms. *After Davidson.*

the mantles. The vital organs are confined to the lower or beak side of the space between the valves, but the greater portion of this space is occupied by two plumose "arms," which serve as breathing organs and also for conducting particles of food to the mouth which lies between them. It was the mistake of regarding these arms as creeping organs that led to the name "brachiopod," or "arm-footed."

In the simpler brachiopods the arms are without a hard shelly support, but in the higher forms calcareous structures are developed in one valve to give rigidity to the arms. These supports may be simple spurs or spirally coiled threads, or loop-like structures. The characteristics of these arm-supports are of great importance in classification, second only to the structure of the opening for the peduncle.

Forty-four genera and 477 species of Cambrian brachiopods have been described. It is significant that of these 229 species belong to the lowest order, in which the peduncle emerges freely between the valves and there is no hinge, and that 188 species belong to a higher order, still without hinge,

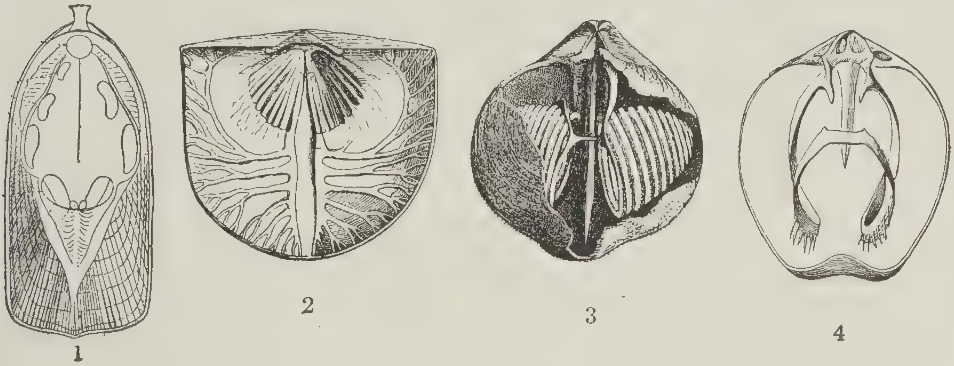

FIG. 83. FOUR TYPES OF BRACHIOPODS

1. Simplest type without hinges; 2. Type with hinge, but without calcareous support for breathing arms; 3. Type with spiral supports; 4. Type with looped supports. Figures 1 and 2 show vascular markings and muscle scars.

but with a slight modification in the peduncular opening. The remaining 110 species have a simple hinge, but there are no representatives of the higher orders with calcareous supports for the arms and complex peduncular passages.

Ostracods. Ostracods are small crustaceans enclosed in a bivalved shell. In the fossil condition only the shells are known: these resemble very closely a half-bean, but they are usually of smaller size than the average bean. The outline varies with the different genera, and details of surface ornamentation are of value in determining species. The Cambrian rocks of the maritime provinces of Canada alone have yielded about forty species of ostracods.

Phyllopods. Like trilobites and ostracods, these organisms are crustaceans; they are closely related to the ostracods, but the shell is not in two pieces and it does not cover

the whole of the body. Some very interesting forms have been obtained from the Cambrian rocks of British Columbia.

Despite the great age and serious metamorphism of most Cambrian strata, some few favoured localities have yielded fossils in an exquisite state of preservation. Not only are the hard parts preserved, but impressions of soft tissue are found, and indications of such delicate organs as the antennæ and limbs of crustaceans. The most remarkable of these rare and beautifully preserved fossils were obtained by Dr. Walcott from shales of Middle Cambrian age near Burgess pass, British Columbia. They include jelly-fish, sea-cucumbers, worms, and some of the higher arthropods with the various organs delicately preserved.

It will be noticed that in the above account only the life of the sea has been mentioned. We know nothing of the continent which doubtless made up most of Canada in Cambrian time, except that it had a weathering rock surface from which rivers brought down mud and sand. Probably it was bare of plant life—a desert—because land plants had not yet come into being. Without land vegetation, one may suppose an equal lack of air-breathing animals. The continent was seemingly a lifeless wilderness.

CAMBRIAN FOSSILS OF THE MARITIME PROVINCES

The fossils of this region are distinctly of an Atlantic type and show relationships to European species. The commonest fossils are trilobites; brachiopods are less numerous; ostracods and other types occupy third place. Common examples are:

Trilobites:

Paradoxides eteminicus, Conocoryphe baileyi, Microdiscus regulus.

Brachiopods:

Protorthis billingsi, Lingulella gregwa.

FOSSILS OF THE POTSDAM SANDSTONE

The Potsdam sandstone of Ontario and Quebec shows few fossils. The one really characteristic species is *Lingulella acuminata*. Worm burrows and the tracks of unknown organisms have been found.

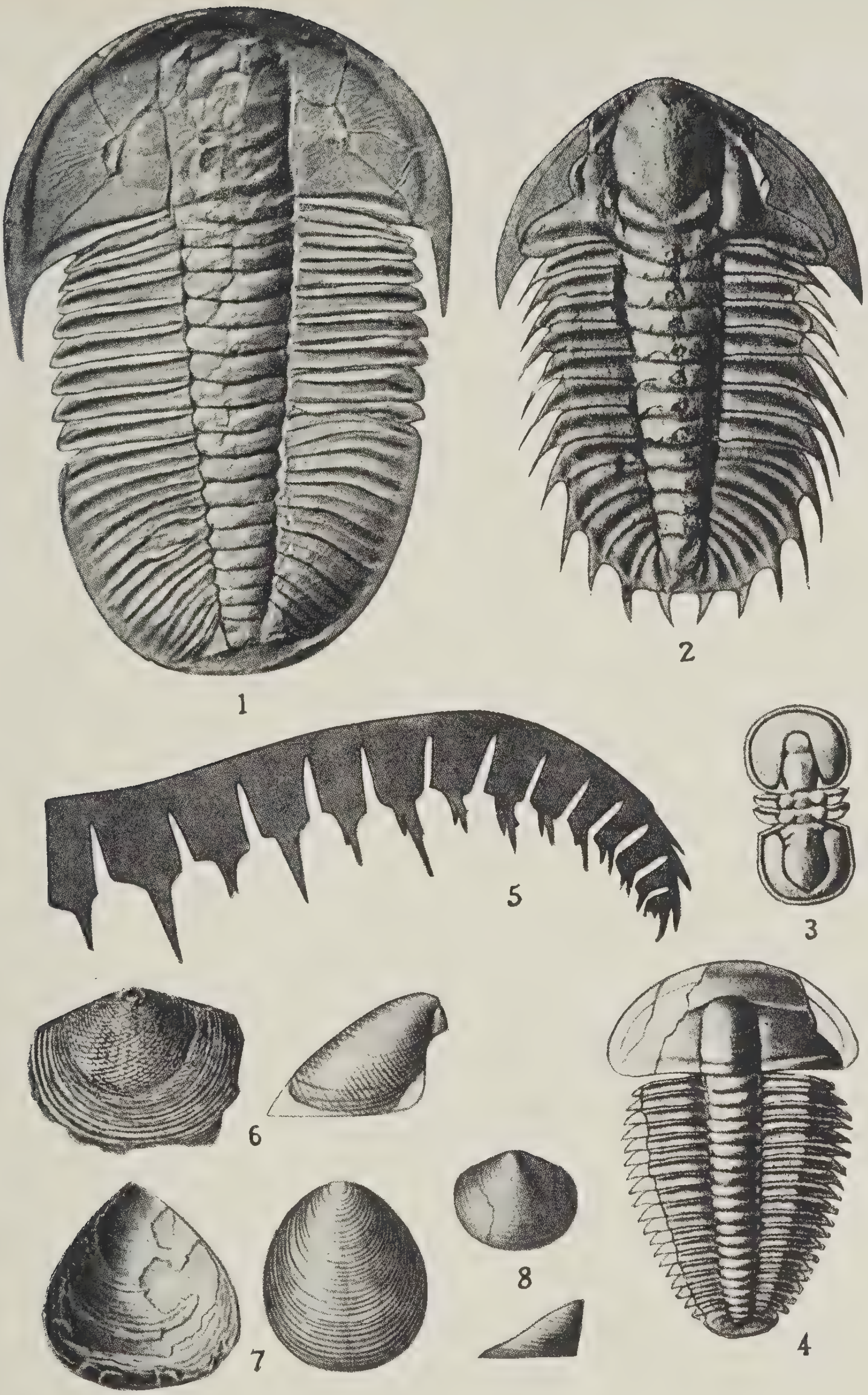

FIG. 84. CAMBRIAN FOSSILS OF BRITISH COLUMBIA

Trilobites: 1. *Ogygopsis klotzi*; 2. *Neolenus serratus*; 3. *Agnostus montis*; 4. *Ptychoparia cordilleræ*. Phyllopod: 5. *Anomalocaris canadensis*. Brachiopods: 6. *Micromitra pannula*, ventral and side views; 7. *Obolus mcconnelli*, pedicle and brachial views; 8. *Acrotreta depressa*, pedicle and lateral views. Nos. 1, 2, 4 and 5 natural size, the other figures greatly enlarged. *After Walcott.*

CAMBRIAN FOSSILS OF THE ROCKY MOUNTAIN REGION

The Cambrian rocks of this region are not rich in fossils throughout, but in places the characteristic species of Lower, Middle and Upper Cambrian are found in abundance and in an excellent state of preservation. The fauna is distinctly of a Pacific type, and while generally similar, it differs from that of the eastern region in detail: for instance, the typical *Paradoxides* is absent from the middle division, but its place is taken by related genera.

The Middle Cambrian is much the richest in fossils; the following characteristic examples are all from that horizon:

Trilobites:

Ogygopsis klotzi, Neolenus serratus, Ptychoparia cordilleræ, Agnostus montis.

Brachiopods:

Obolus mcconnelli, Micromitra pannula, Acrotreta depressa.

Phyllopod:

Anomalocaris canadensis.

CHAPTER VI

THE ORDOVICIAN PERIOD

Cambrian time was followed by a long period to which the name *Ordovician* has been given, as the rocks of this system were first studied in Wales, a part of which was inhabited in Roman times by a tribe called the Ordovices.

PHYSICAL EVENTS OF THE ORDOVICIAN IN NORTH AMERICA

We have seen that the later stages of Cambrian time were marked by a great advance of the sea on the continent. The close of the Cambrian and the beginning of the Ordovician seem to indicate a general withdrawal of the water from the present land areas. The conditions are not well understood for the whole continent, but it is known that a gradually receding sea occupied the country from eastern Ontario south and east through parts of the maritime provinces and the eastern United States to the Atlantic ocean. At the same time a pronounced submergence occurred in Nevada and Utah. This period of emergence and of deposition in rather confined areas represents the Lower Ordovician or *Canadian* time.

Now followed a downwarping of the eastern interior of the continent whereby seas, not in connection with the Atlantic ocean, covered large areas in the eastern United States and the southern part of eastern Canada. It is believed that this submergence finally became so pronounced that a broad connection was established across the highlands of Canada with the waters of the Arctic ocean. Many oscillations of land and water occurred during this time, which is known as the Middle Ordovician, and is sometimes erroneously called *Champlainian*.

The Middle Ordovician seas having largely withdrawn, a new invasion of waters spread over the continent from the Gulf of Mexico northward and eventually became united with

a great flood advancing southward from the Arctic ocean. This epoch is the Upper Ordovician, and is called *Cincinnatian* by American geologists.

The physical conditions in the Cordilleran region are not so well understood, but the Rocky Mountain geosyncline continued to be an area of depression, with the result that

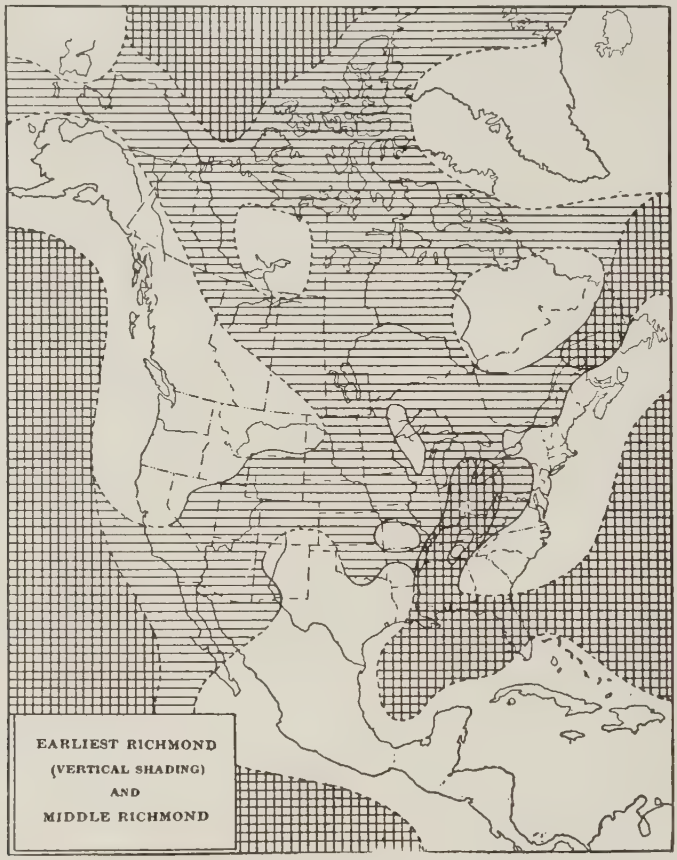

FIG. 85. PALÆOGEOGRAPHIC MAP OF NORTH AMERICA IN UPPER ORDOVICIAN TIME

White areas, land; vertically lined areas, water in early Richmond time; horizontally lined areas, water in middle Richmond time. *From Pirrson and Schuchert, "Textbook of Geology."*

Ordovician strata were deposited on top of the great accumulations of Cambrian sediments.

The close of Ordovician time was marked by a disturbance of the continent in the Atlantic border region. This or later disturbances seriously affected the Ordovician strata of the maritime provinces, throwing them into folds and greatly altering their original physical characteristics. As the Green mountains of Vermont and their southern

extension, the Taconic range, were first uplifted at this time, the event has been called the *Green Mountain* or *Taconic revolution.*[1] It is to be noted, however, that the Ordovician rocks of the interior of the continent show scarcely any effect of this upheaval of the region along the Atlantic coast.

The Ordovician as a whole was a period of limestone formation, although shales form a prominent element in the strata of certain localities. On the other hand, sandstones occur to a very limited extent. The movements of land and water were on a grand scale in Ordovician time; the formations are heavier and of greater geographical extent than is usual in any later systems.

THE ORDOVICIAN SYSTEM IN CANADA

The Canadian occurrences of Ordovician strata may be grouped in areas as follows:

1. Acadian Area. If a line be drawn along the axis of Lake Champlain, thence north to the St. Lawrence river, and down the river to the ocean, it will cut off from the rest of Canada an area which has been greatly disturbed, not only by the Taconic revolution above referred to, but by subsequent earth movements of great magnitude. This line marks the location of a great fault—the Champlain fault—as the strata on the two sides have been thrown hundreds of feet out of accord. The Ordovician rocks to the east of the fault have been so upturned and metamorphosed, and the characteristic fossils so destroyed, that their study is attended with difficulties far exceeding those of the other Ordovician regions of Canada. Strata of this age occur in belts of limited extent with a general north-east and south-west trend; the chief of these are as follows:

(*a*) The eastern townships of Quebec.

(*b*) The south-eastern part of the Peninsula of Gaspé.

(*c*) Central New Brunswick from Chaleur bay south-westward across the province.

(*d*) Northern Nova Scotia from Minas basin to the eastern point of the mainland.

[1] In the light of recent investigations this event scarcely deserves the name "revolution." It was formerly regarded as of great magnitude.

2. Anticosti Island. The northern coast of the island of Anticosti is occupied by Ordovician rocks which are undisturbed, as the island lies north of the Champlain fault. Well-preserved fossils may be obtained in abundance from the exposures along this coast.

3. St. Lawrence Area. Eastern Ontario and western Quebec, from the Potsdam sandstone area to the Champlain fault and along the north shore of the St. Lawrence river to a short distance below the city of Quebec.

4. Ontario Area. Ordovician rocks cross the province of Ontario in a broad belt extending from Lake Ontario to Georgian bay, and reappearing on the north shore of Manitoulin island and on the islands between Manitoulin and the mainland. The belt is widest in the south, forming the shore of Lake Ontario from Kingston to beyond Toronto; on Georgian bay it reaches from Matchedash bay to Owen sound.

A great system like the Ordovician is naturally divisible into series, and the series into formations. While the series may be recognised the world over, the lesser divisions, formations, are necessarily of limited extent. As an example of the subdivision and classification of the rocks of the Ordovician system, those occurring in Ontario are arranged as follows:

THE SEQUENCE OF ORDOVICIAN ROCKS IN ONTARIO

System	Series	Formation
Ordovician	Upper Ordovician or Cincinnatian	Richmond Lorraine Utica
	Middle Ordovician or "Champlainian"	Collingwood Trenton Black River Lowville Pamelia Aylmer (Chazy)
	Lower Ordovician or Canadian	Theresa (Beekmantown)

These formations consist of rock differing in composition and appearance, but not always sufficiently so to enable one

to state the formation from which a given sample has been taken. As each formation, however, has its own distinctive fossils, an examination of these affords certain evidence as to the age of the rock.

In the area under consideration successively higher formations are encountered as one goes westward from the Pre-cambrian axis. Naturally, on the east side of the axis the younger formations are encountered as one advances eastward. The formation at Kingston is Black River, and at Toronto, Lorraine.

FIG. 86. SKETCH MAP OF EASTERN CANADA SHOWING IN BLACK THE CHIEF AREAS OF ORDOVICIAN ROCKS

Small areas also occur in Nova Scotia, and the area in New Brunswick dotted in Fig. 102 is in part Ordovician.

5. Hudson Bay Area. Ordovician rocks occupy a considerable area to the west of Port Nelson and Fort Churchill on the west side of Hudson bay.

6. Arctic Islands Area.

7. Manitoba Area. Ordovician rocks, with a width of about 100 miles, extend from the international boundary northward along the flank of the Pre-cambrian axis to Latitude 56° N.

8. Rocky Mountain Area. Ordovician rocks overlie the Cambrian strata in the middle ranges of the Rocky mountains.

ECONOMIC PRODUCTS OF ORDOVICIAN ROCKS

The limestones of the Ordovician system are extensively quarried for building, for lime and cement-making, for concrete, and for macadam. Large quarries are operated in Middle Ordovician strata at Hull, Ottawa, Montreal, Quebec, Kingston, Longford Mills, and other places. The bituminous shales of the Collingwood and Utica formations were distilled for oil before the discovery of petroleum, and may again be required for this purpose.

Middle Ordovician rocks yield excellent building-stone at Tyndall, Manitoba, and the upper division has been quarried at Stony mountain and elsewhere in Manitoba for crushed rock and lime-making.

Marble is obtained from Ordovician rocks in the metamorphic area of the eastern townships of Quebec.

The natural gas of central Ohio and of the Leamington and Norfolk and Elgin county fields in Ontario is derived from strata of this age by boring through the overlying rocks.

Most of the celebrated mineral waters of Ontario and Quebec issue from Ordovician rocks, more particularly in the St. Lawrence area.

LIFE OF THE ORDOVICIAN

Compared with that of the Cambrian, the life of the Ordovician is more varied and much more abundant; it has been called the "first great fauna." The predominance of limestone attests the great amount of life, as many of these rocks are visibly composed of the remains of shelled organisms.

ORDOVICIAN PLANTS

Ordovician plants are known by distinct impressions which leave no doubt as to their origin from seaweeds which were entombed on the floor of the sea. Terrestrial plants are unknown.

ORDOVICIAN INVERTEBRATES

Plant remains being meagre and vertebrates almost entirely absent, the Ordovician life was essentially one of inverte-

brates. As the time was very long and many changes took place, it is somewhat difficult to speak of the life as a whole; this difficulty is increased by the fact that no classes and few orders are absolutely confined to the period. On the other hand, certain groups of organisms reached their maximum development; these are to be regarded as particularly characteristic, but they do not by any means represent the whole life. These outstanding groups are brachiopods, trilobites, graptolites, cystids, receptaculites, and possibly bryozoans. A brief account of the life of the time follows.

Sponges. Many sponges occur, particularly in the lower

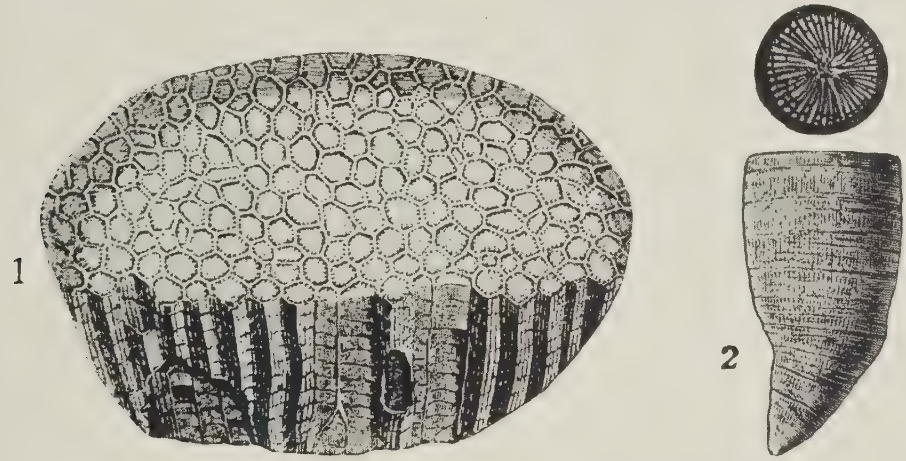

FIG. 87. ORDOVICIAN CORALS

1. *Columnaria halli* 2. *Streptelasma corniculum. After Billings and Lambe.*

part of the system; in Canada, however, examples of this kind of creature are rare.

Receptaculites. These very characteristic Ordovician creatures are of doubtful zoological position, but are probably allied to the sponges. They build hollow, vase-shaped skeletons of considerable size—up to a foot in diameter. The wall is composed of an inner and an outer layer connected by pillars. The fossils are easily recognised, even in fragments, by the peculiar curved, radial arrangement of the pillars, which is reflected on both the inner and outer wall. Beautifully silicified specimens are common at Paquette's rapids in Ontario, and very large examples are frequent in the Ordovician rocks of Manitoba.

Corals. Corals are small soft-bodied animals in which a

single body cavity performs all the vital functions, *i.e.* there is no intestine or circulatory system. Corals may live singly or in colonies; in either case they secrete a skeleton of carbonate of lime which is correspondingly single or compound. *Streptelasma* is a common example of single Ordovician corals, and *Columnaria* of the compound type. While corals are more abundant than in the Cambrian, they do not reach the important position which they fill in later geological periods.

Graptolites. Hydrozoa are cœlenterate animals like corals, but of simpler organisation and smaller size. Graptolites are thought to be hydrozoans which build compound skeletons of horny matter instead of lime. In the fossil

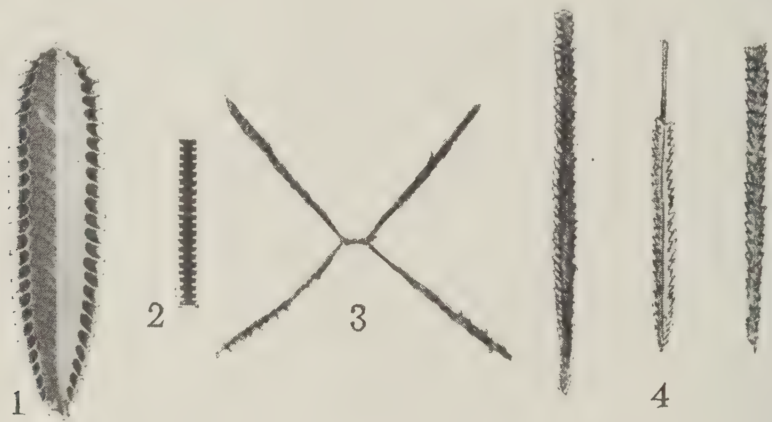

FIG. 88. ORDOVICIAN GRAPTOLITES

1. *Phyllograptus angustifolius*; 2. *Climacograptus typicalis*; 3. *Diplograptus foliaceus.* Natural size. *After Hall and Ruedemann.*

condition, the skeletons of graptolites have been reduced to graphite and appear like pencil marks on slabs of rock. In life the colonies were free and drifted with the currents of the ocean. This habit, together with the fact that they are short-range forms, makes them very valuable for the determination of the different formations. These organisms are among the most characteristic of Ordovician fossils. *Diplograptus* and *Monograptus* are typical simple forms, while *Phyllograptus* and *Tetragraptus* exemplify the more complex kinds.

Echinoderms. These organisms, as the name implies, are characterised by the possession of a hard outer crust or shell composed of plates or rods of carbonate of lime. There are two rather distinct types of echinoderms—those that are fastened by a stalk to the sea floor, such as the existing sea

lilies, and those which are capable of locomotion, like the star-fishes and sea-urchins of to-day.

In the Ordovician, sea-urchins are unknown and star-fish are represented by rare examples only. The fixed or stalked

FIG. 89. ORDOVICIAN CRINOIDS AND CYSTIDS

1. *Cupulocrinus humilis*; 2. *Ottawacrinus typus*; 3. *Pleurocystis squamosus*; 4. *Reteocrinus alveolatus*; 5. *Iocrinus subcrassus*; 6. *Glyptocrinus decadactylus*; 7. *Malocystis murchisoni*. All figures natural size. *After Springer and Hall, and from original photographs.*

type, however, is common; of these, two different kinds are found, known as *cystids*, and *crinoids* or *sea lilies*.

Cystids are stalked echinoderms of simple organisation and without a circlet of waving arms at the top; they are the simplest of all echinoderms, and reached their maximum development in the Ordovician. *Malocystis* and *Pleurocystis* are the commonest genera in the Ordovician rocks of eastern Canada.

Crinoids, or sea lilies, resemble cystids in the possession of a jointed column or stem and a plated cup or body; they differ, however, by having a circlet of waving arms above the cup. The popular name "sea lily" is given on account of the general resemblance to a lily, not because crinoids are plants or in any way related thereto.

Crinoids were so abundant in the Ordovician that, in certain places, whole layers of rock are made up of the disassociated plates. Owing to the disintegration of the remains after death, entire specimens are found only in favoured localities. The Middle Ordovician rocks at Kirkfield, Ontario, have yielded a remarkable assemblage of crinoids, and the strata of the upper division at Toronto are in places filled with columns although whole specimens are rare. Common genera are *Archæocrinus*, *Glyptocrinus*, *Heterocrinus*, *Cupulocrinus*, and *Dendrocrinus*.

Although crinoids were numerous in the Ordovician, they attained a much greater development later; they are not so typical of the Ordovician as are the cystids.

Brachiopods. These organisms attained a remarkable development, reaching, if not their maximum, a position only equalled by that of the next great system. The thin-shelled hingeless types, so characteristic of the Cambrian, are less in evidence, their place being taken by hinged forms which, however, are without a calcareous support for the arms. The highest type has not yet made its appearance in force. Common genera of the Canadian Ordovician rocks are *Hebertella*, *Rafinesquina*, *Dalmanella*, *Plectambonites*, *Zygospira*, *Dinorthis*, and *Platystrophia*. *Plectambonites sericeus* is so common both in the middle and upper divisions that thick layers of limestone are composed almost entirely of its remains.

Bryozoa. These organisms, almost unknown in the Cambrian, appear with extraordinary profusion in the Ordovician, and maintain a position of great importance throughout the whole of the Palæozoic era. By reason of their great numbers and wide distribution, and the limited range in time of individual species, bryozoans are of the highest value in determining the formations of the Ordovician and later Palæozoic systems. On the other hand, their study is attended

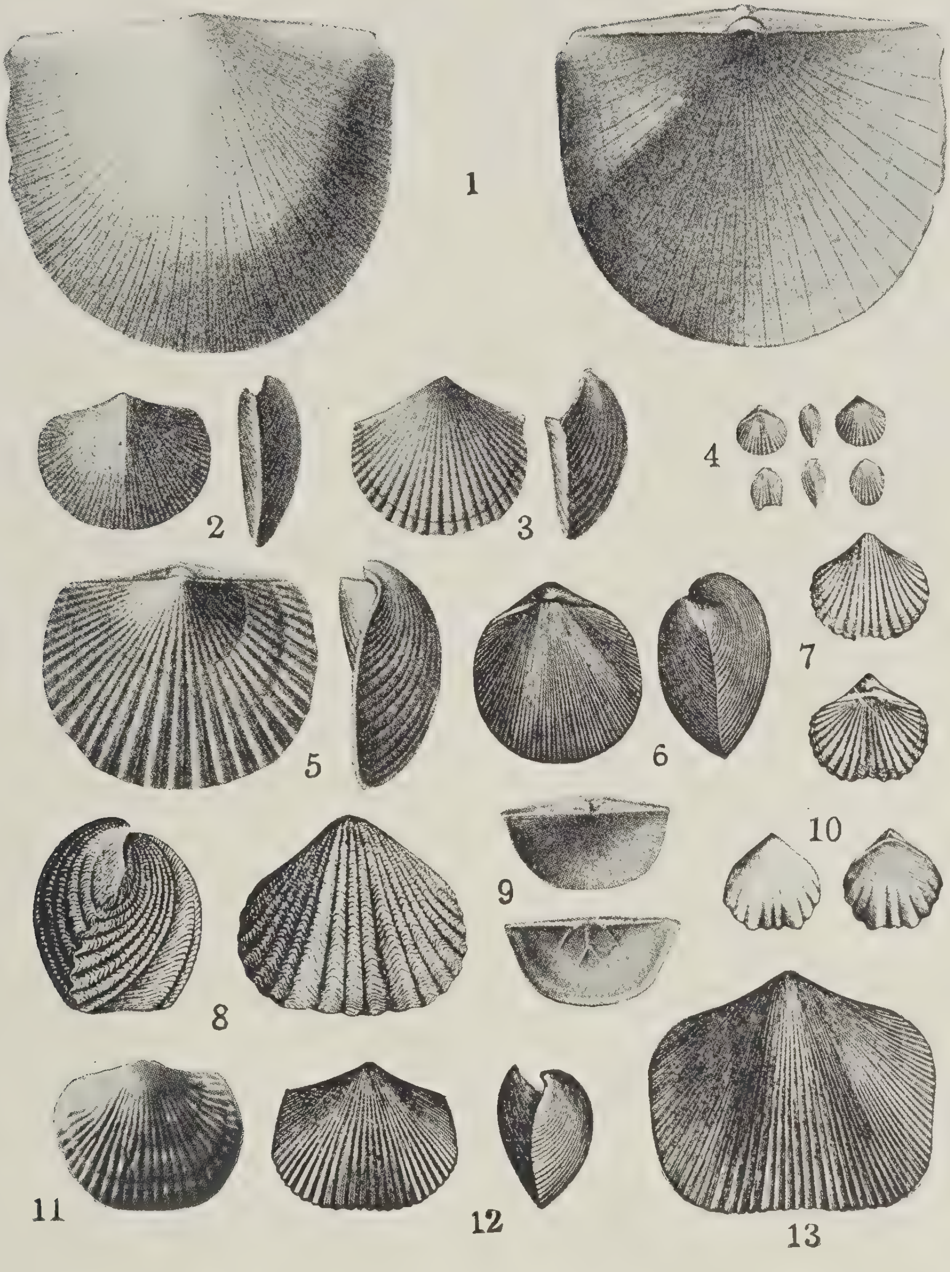

FIG. 90. ORDOVICIAN BRACHIOPODS

1. *Rafinesquina alternata*, brachial and pedicle views; 2. *Dalmanella testudinaria*, brachial and side views; 3. *Orthis tricenaria*, brachial and side views; 4. *Zygospira recurvirostris*; 5. *Dinorthis pectinella*, pedicle and lateral views; 6. *Catazvga headi*, brachial and lateral views; 7. *Zygospira modesta*, brachial and pedicle views; 8. *Rhynchotrema capax*, lateral and pedicle views; 9. *Plectambonites sericeus*, external of brachial and internal of pedicle valves; 10. *Camerella volborthi*, brachial and pedicle views; 11. *Dinorthis subquadrata*; 12. *Hebertella borealis*, pedicle and lateral views; 13. *Hebertella imperator*, pedicle view. All figures natural size. *After Billings and others.*

with many difficulties which detract from their value in the hands of the amateur.

Bryozoans are extremely small, sack-shaped animals with a simple coiled intestine and a circlet of waving arms around the mouth. They live in colonies and build a compound skeleton resembling that of a compound coral. The bryozoan skeleton, however, is very much finer, as the little individuals are seldom of greater diameter than a needle. The skeleton

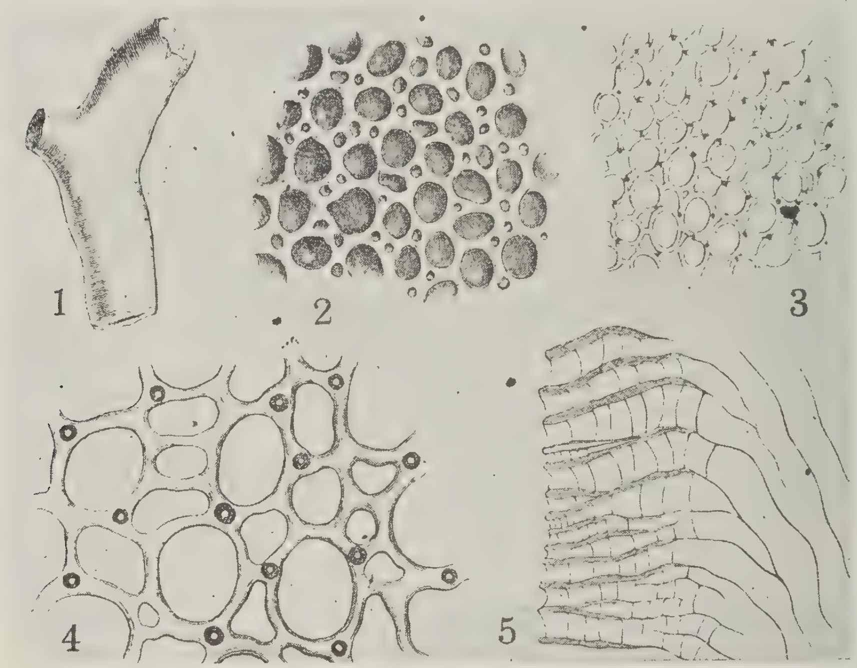

FIG. 91. STRUCTURE OF LONG-CELLED OR TUBULAR BRYOZOANS

1. Portion of a branching colony, natural size; 2. Surface enlarged showing the openings of the tubes; 3. Tangential section, showing the tubes in cross section and the small hard nodes (*acanthopores*); 4. The same greatly enlarged; 5. Vertical section, showing the tubes and the cross partitions (*diaphragms*). *After Nicholson.*

of a typical Ordovician bryozoan may be sub-globular, hemispheric, cake-shaped, branching like a tree, or forming a crust over other objects. By the naked eye the average bryozoan would scarcely be recognised as a fossil. If the surface be examined with a lens, it is seen to be covered with small pits; these pits are the openings of the cells in which the individual creatures lived. If the fossil be broken across, the fractured surface presents a fibrous appearance; the fibres are really little tubes closely set together. Each tube represents the cavity in which a bryozoan lived, and the pits

on the surface are the openings of these tubes. All bryozoans do not show this tubular structure, but the great majority of Ordovician bryozoans do. Common genera are *Prasopora, Monticulipora, Dekayella, Batostoma,* and *Hallopora.*

Gastropods. These organisms, the belly-footed molluscs, secrete a single-valved spiral or saucer-shaped shell which is borne on a hump at the posterior part of the body. The familiar garden snail will serve as an example of the class. Gastropods of a simple kind are quite abundant in certain

FIG. 92. ORDOVICIAN OSTRACODS AND BRYOZOANS

Ostracoda: 1. *Beyrichia tuberculata*; 2. *Leperditia hisingeri.* Bryozoa: 3. *Hallopora dalei*; 4. *Bythopora delicatula*; 5. *Dekalella ulrichi*; 6. *Prasopora selwyni.*

strata of the Ordovician, but they do not attain the important position which they fill at a later time.

Typical Ordovician gastropods, each representing a different type, are *Hormotoma, Raphistomina, Bellerophon,* and *Maclurea.* The latter genus is particularly characteristic of the period.

Pelecypods. The bivalved molluscs, of which the common clam is a typical example, are called pelecypods because they have a hatchet-shaped foot or creeping organ. These creatures form the great bulk of the shell-fish of the present day, and they existed in vast numbers throughout the geological ages. Almost unknown in Cambrian time, they are represented in the Ordovician by thin-shelled, primitive types which are

without the complicated hinge apparatus characteristic of modern forms.

Pelecypods are rare in Lower Ordovician rocks. *Cyrtodonta* and *Ctenodonta* are common Middle Ordovician genera. More

FIG. 93. ORDOVICIAN GASTROPODS

1. *Hormotoma anna* (Beekmantown); 2. *Hormotoma trentonensis* (Trenton); 3. *Raphistomina canadensis* (Beekmantown); 4. *Maclurea logani* (Black River); 5. *Liospira vitruvia* (Trenton); 6. *Sinuites cancellatus* (Trenton). All figures natural size.

numerous species occur in the upper division, and they may be secured in abundance from the strata exposed near Toronto. Particularly numerous are *Modiolopsis*, *Byssonychia*, and *Pterinea*.

Cephalopods. These are the largest, the most highly specialised, and the strongest and most predaceous of the molluscs. The class includes such forms as the squids, cuttle-

fish, and pearly nautilus. The latter organism is closely related to the type of cephalopod which existed in Palæozoic time, and may be described as typical of the class.

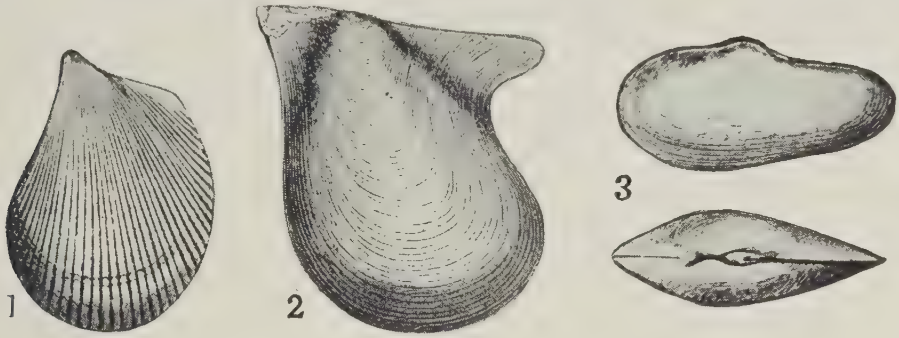

FIG. 94. ORDOVICIAN PELECYPODS

1. *Byssonychia radiata* (Lorraine); 2. *Pterinea demissa* (Lorraine); 3. *Ctenodonta nasuta* (Black River). All figures about seven-eighths natural size.

The shell of the pearly nautilus, which sometimes attains a diameter of a foot or more, is like a gradually tapering cone

FIG. 95. ORDOVICIAN PELECYPOD

Modiolopsis modiolaris in Lorraine shale.

which has been coiled symmetrically in one plane. The interior is divided into compartments by transverse partitions, known as *septa*, which are connected with one another by a small

tube called the *siphuncle.* The animal lives in the outermost compartment; the inner compartments are empty, and probably serve as an apparatus to keep the creature at fixed depths in the water. The outer layer of the shell shows broad transverse strips of white and brown. When this layer is removed the shell presents a beautiful pearly surface, whence the name "pearly nautilus." Cephalopods of this type are called *Nautiloids.*

FIG. 96. NAUTILUS POMPILIUS, A RECENT NAUTILOID, WITH THE SHELL REMOVED ON ONE SIDE

(*a*) The mantle enclosing the body and passing backwards as a narrow tube, the siphon; (*b*) Dorsal lobe of mantle; (*c*) Hood; (*d*) Funnel; (*h*) Muscle; (*o*) Eye. *After Owen.*

In the Ordovician, creatures very like the pearly nautilus abounded. Many of them differed, however, in having straight instead of coiled shells; they are known as *Orthoceras* in consequence. A straight form with a rapidly tapering cone, *Gonioceras,* is very characteristic of the Middle Ordovician time; *Endoceras* is a type of large size with a relatively big siphuncle; *Trocholites* and *Eurystomites* are coiled forms. *Actinoceras crebriseptum* is one of the commonest and most striking fossils found in the rocks near Toronto.

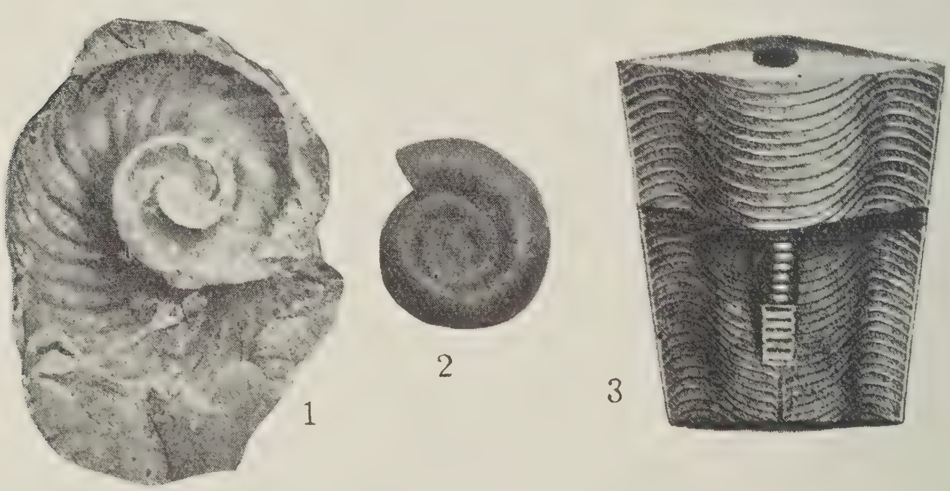

FIG. 97. ORDOVICIAN NAUTILOIDS

1. *Plectoceras halli*; 2. *Trocholites ammonius*; 3. *Gonioceras. From specimens and from "Lethæa Geognostica."*

TRILOBITES. Trilobites reached their maximum development in the Ordovician. All the Cambrian species and most

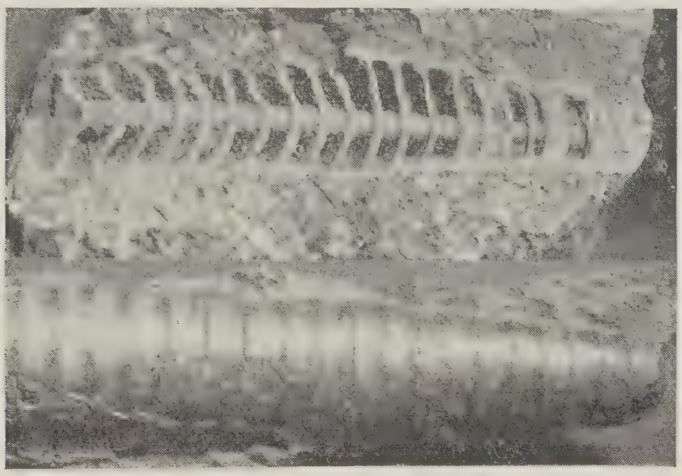

FIG. 98. ACTINOCERAS CREBRISEPTUM FROM THE LORRAINE ROCKS AT TORONTO

The bottom specimen has the outer shell removed, exposing the edges of the septa; the top specimen is half worn away, showing the septa and the siphuncle.

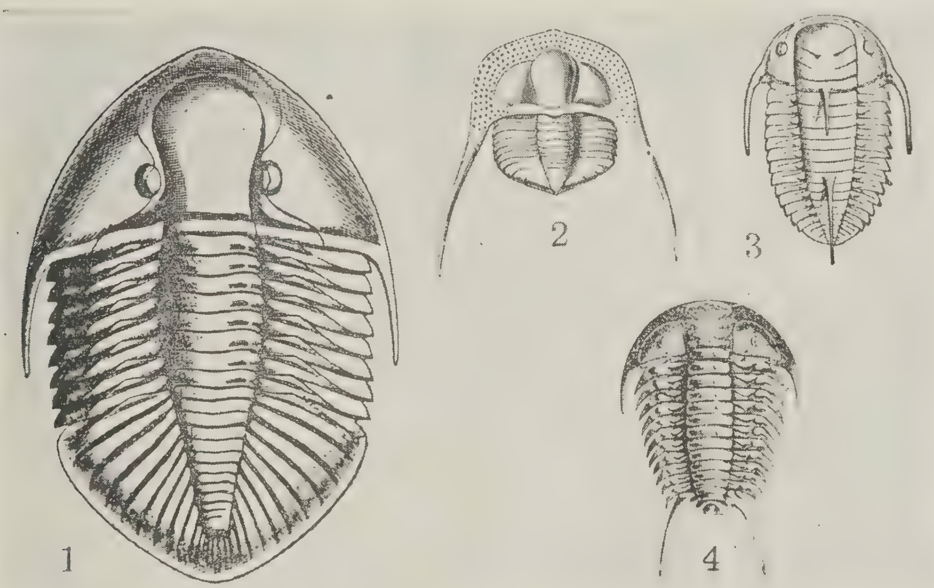

FIG. 99. ORDOVICIAN TRILOBITES

1. *Ogygites canadensis* (Collingwood); 2. *Cryptolithus tesselatus* (Trenton to Lorraine); 3. *Triarthrus spinosus* (Utica and Collingwood); 4. *Ceraurus pleurexanthemus.* All figures about natural size.

of the genera have become extinct, their place being taken by new races which belong, for the most part, to the intermediate

type, although a few of the lowest type survive and a few of the highest type are introduced. Common genera are *Isotelus, Calymene, Trinucleus, Triarthrus,* and *Cheirurus*.

Ostracods. The remains of the small shells of these creatures are abundant in the Ordovician rocks of certain localities.

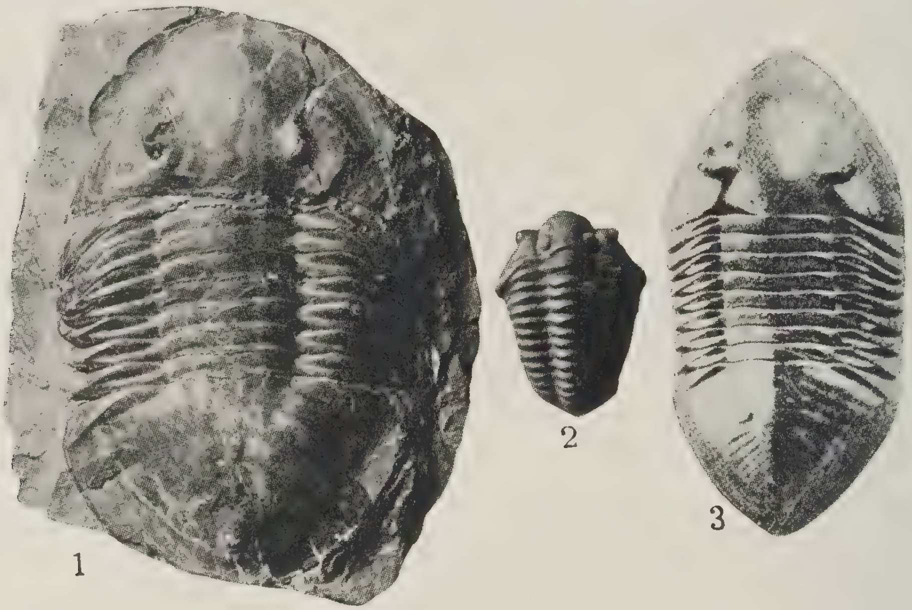

FIG. 100. ORDOVICIAN TRILOBITES

1. *Isotelus maximus* (Lorraine); 2. *Calymene senaria* (Trenton); 3. *Isotelus gigas* (Trenton).

Leperditia canadensis is very common, and may be collected in extraordinary numbers from the exposures near L'Original in Ontario.

Vertebrates. Animals with backbones have not been found in the Ordovician rocks of Canada, but fragmentary remains of a few primitive fish have been discovered in Colorado, Wyoming, and South Dakota.

CHAPTER VII

THE SILURIAN PERIOD

This period, like the two preceding, derives its name from the locality in which it was first studied—in this case, the south part of Wales and the adjoining portions of England, which region was formerly inhabited by a tribe of Britons known as "Silures."

PHYSICAL EVENTS OF THE SILURIAN IN NORTH AMERICA

We have seen that the Ordovician was brought to a close by a physical disturbance, called the Taconic revolution, which to some extent displaced the rocks of earlier time so that the Silurian strata rest upon them with more or less unconformity throughout the Appalachian region of the United States and the maritime provinces of Canada. In the continental interior the disturbance was much less extensive, as the Silurian rocks are separated from the earlier strata by only a slight disconformity which in places is scarcely perceptible.

While Ordovician time is marked by great continental elevations and depressions, with wide-spread seas and consequent extended formations, the Silurian as a whole witnessed only one great depression with many minor oscillations. The formations of the Silurian seas, therefore, are more local and of less extent than those of the Ordovician.

The initial submergence of the period seems to have affected the Acadian region, for the lowest strata are found in Nova Scotia and Anticosti island. Before the close of Lower Silurian time, the seas had invaded the interior of the continent and the middle division of the period witnessed the maximum expansion, with waters covering a large part of the continent, which, however, presented the appearance of a vast archipelago. Upper Silurian time was largely an epoch of emergence, with the marine waters gradually withdrawing from the interior region and later from the Arctic area of submergence.

THE SILURIAN SYSTEM IN CANADA

The exposures of Silurian rocks in Canada may be grouped in areas as below:

1. Acadian Area. Silurian rocks occur as narrow north-east and south-west strips in Newfoundland and Nova Scotia; they form the south side of the island of Anticosti, and occur over a wide area in the northern part of New Brunswick and adjacent portions of Quebec. The rocks are mostly black, red and green shales, with argillaceous limestones and some sandstone.

2. Ontario Area. Strata of this period form a wide belt crossing the province of Ontario from the Niagara river to Manitoulin island. The lower rocks are sandstones and shales, but with the deepening seas of the Middle Silurian these gave place to heavy dolomites, which were again followed by shales in the closing stages of the period.

As in the case of the Ordovician, this area will be used to exemplify the subdivision of the Silurian system into series and formations.

THE SEQUENCE OF SILURIAN ROCKS IN ONTARIO

System	Series	Formation
Silurian	Upper Silurian or Cayugan	Monroe and Bertie Salina
	Middle Silurian or Niagaran	Guelph Lockport Rochester Clinton
	Lower Silurian or Oswegan	Medina Cataract

The Cataract, Medina, Clinton, and Rochester are composed chiefly of sandstones and shales. All these rocks are of a soft nature, but the overlying Lockport is a heavy dolomitic limestone deposited in the Middle Silurian sea at the time of its greatest extension and deepest water. In consequence of the occurrence of this hard, heavy stone above the

soft underlying formations, a striking feature in the topography of the province has arisen. Millions of years have intervened between the time that these rocks were lifted out of the sea and the present. During all this time the forces of erosion have been at work, with the result that the softer rocks have been worn away except where the hard Lockport dolomitic limestone has afforded them protection. The line to which the erosion has advanced westward is marked, therefore, by a steep cliff or escarpment (cuesta) which reaches from Queenston heights to Manitoulin island,

FIG. 101. THE NIAGARA CUESTA

except where it is interrupted by the waters of Lake Huron. The province is divided, therefore, into two topographic units —the western upland and the eastern lowland, separated by the significant escarpment which is known to the inhabitants of the region as the *Hamilton Mountain*. Niagara Falls owes its existence to the same set of causes; for had there been no escarpment there would be no falls, and no escarpment would have been formed had the arrangement of hard and soft rocks been different. To the sequence of events in the far-distant Silurian sea we owe the present configuration of the province and the possession of one of the scenic wonders of the world.

From the above remarks it is apparent that the soft lower

rocks have been washed away except where they are covered by the Lockport stone; in consequence, these formations have little or no lateral extent and are to be seen only in the face of the cliff. Splendid opportunities for their study, however, are afforded in the gorge of the Niaraga river and along the face of the escarpment from Queenston heights to Manitoulin island.

3. Hudson Bay Area. Silurian rocks form the west coast of Hudson bay from the mouth of the Ekwan river to Cape Churchill.

4. Manitoba Area. A belt of Silurian rocks occupies

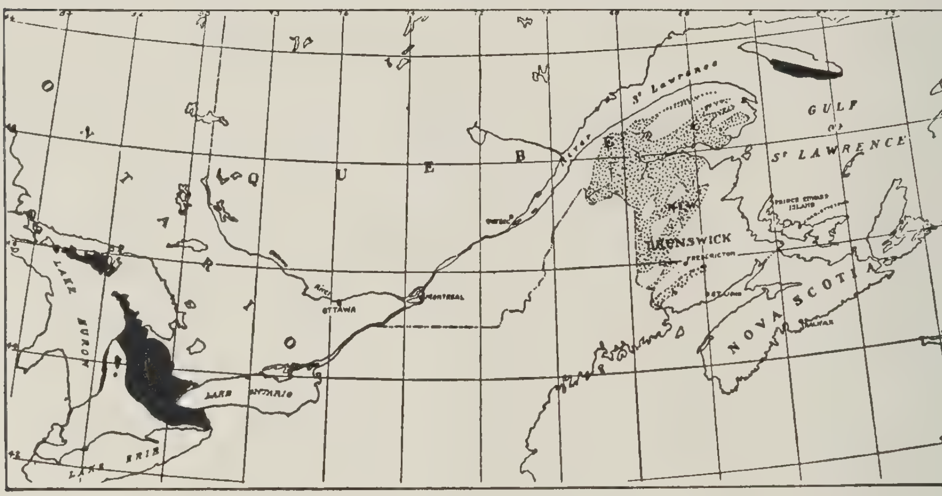

FIG. 102. SKETCH MAP OF EASTERN CANADA SHOWING IN BLACK THE CHIEF AREAS OF SILURIAN ROCKS

The dotted area is chiefly Silurian, but includes some Devonian towards the north and some Ordovician towards the south. Small areas of Silurian rocks also occur in Nova Scotia.

the country between Lake Winnipeg and Lakes Manitoba and Winnipegosis. The rocks are whitish, yellowish, and cavernous dolomites, passing into yellowish and reddish calcareous shales.

5. Rocky Mountain Area. Silurian strata overlie the Ordovician beds in the eastern ranges of the Rocky mountains. On the Canadian Pacific Railway dolomitic limestones and white quartzites occur to a thickness of 1850 feet. The belt seems to widen toward the north and to reach into Alaska.

ECONOMIC PRODUCTS OF SILURIAN ROCKS

The Silurian strata of the Acadian region contain no deposits of economic importance. Their original composition

and the results of subsequent deformation have rendered them unfit for building purposes.

In Ontario sandstones are quarried from the Cataract formation at a number of points along the face of the Niagara cuesta, particularly at the forks of the Credit river, north of Toronto. This stone, both grey and brown, has been used extensively in Toronto and other places in western Ontario. The heavy limestones and dolomites of the Lockport and Guelph formations are used for building and lime-making at

FIG. 103. SKETCH MAP OF CENTRAL CANADA SHOWING THE AREAS COVERED BY PALÆOZOIC ROCKS

Ordovician, black; Silurian, dotted; Devonian, black with white dots.

Queenston, Hamilton, Guelph, Owen Sound, and Wiarton. Hard cherty layers of the Lockport formation yield an excellent material for road-making, and the Silurian rocks of Manitoba are employed for crushed stone.

The shallowing seas and desert climate of later Silurian time permitted the evaporation of sea water, with the consequent deposition of beds of gypsum and salt. Gypsum is extensively quarried from these strata at Paris and Caledonia in Ontario, and near Gypsumville in northern Manitoba. Salt is produced in large amount from the Silurian rocks of western Ontario, particularly near Windsor. Deep holes are bored through the overlying rocks into the salt-bearing strata.

Water is allowed to pass down the bore-holes, and the resulting brine is pumped up and evaporated.

CORRELATION OF SILURIAN FORMATIONS

The formations of the Silurian system in Ontario have been given in some detail; the rocks of the other areas are similarly divided into formations, but these formations are not the same, and they do not bear the same names. Nevertheless, the formations of the Silurian or of any other system, in any part of the world, may be compared with one another. Such comparisons are usually called *correlations*, and they are expressed by means of correlation tables.

The following table is introduced as an example; it shows the correlation of the Silurian rocks of Arisaig, Nova Scotia, as determined by Williams, with those of Ontario and of England.

CORRELATION TABLE OF THE SILURIAN FORMATIONS OF NOVA SCOTIA, ONTARIO, AND ENGLAND

System	Formation		
	Nova Scotia	Ontario	England
Silurian	Stonehouse	——	Ludlow (part)
	Moydart	Lockport	Wenlock
	McAdam	Rochester	Upper Llandovery
	Ross Brook	Clinton	Lower Llandovery
	Beech-hill Cove	Medina and Cataract	Lower Llandovery

LIFE OF THE SILURIAN

In many respects the general life of this period is similar to that of the Ordovician. Trilobites, brachiopods, cephalopods, and bryozoans still abound; graptolites and cystids, however, show a marked decline; sponges, corals, and crinoids occur in greater profusion than before. A new type of life, the eurypterids, disputes the supremacy of the seas with the trilobites; fishes occur in some abundance; and the first terrestrial plants make their appearance.

While the Silurian life of the whole world is *similar*, it is by

no means *identical* in the different continents. Even in North America the life differs in the different basins of deposition. The fossils of the Acadian area resemble those of Ontario, but only a few species are identical. The Silurian fossils from the Hudson Bay and Manitoba areas differ from those of Ontario

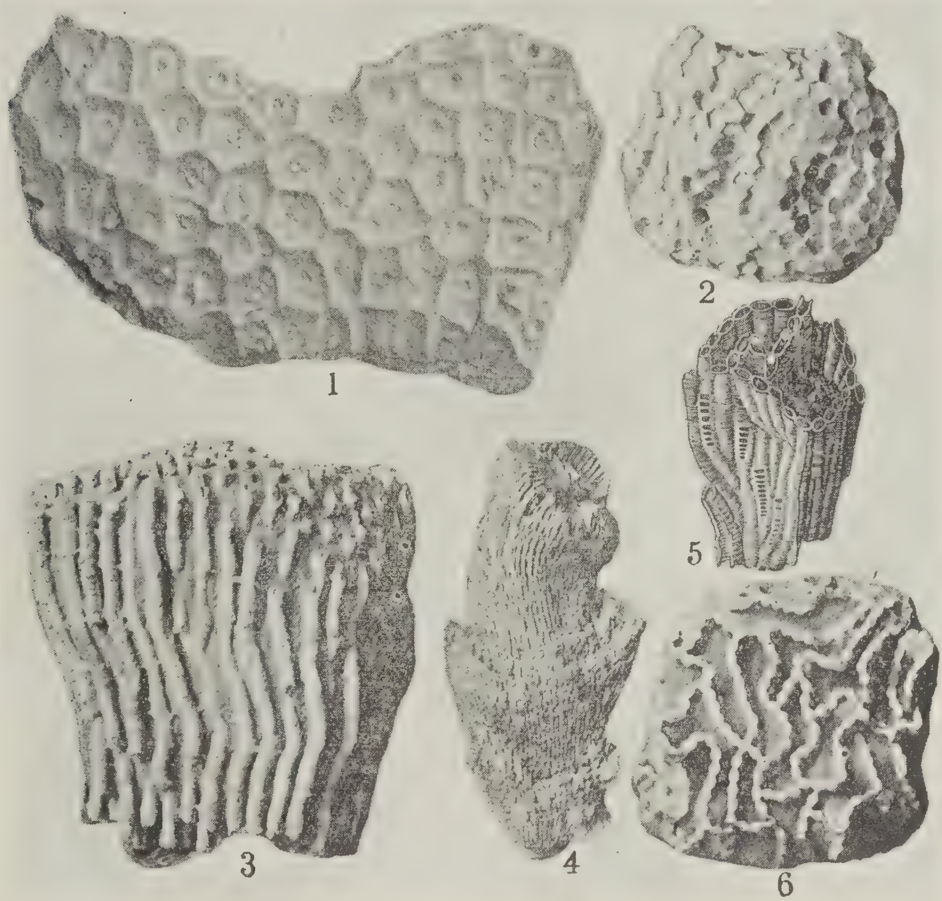

FIG. 104. SILURIAN CORALS

1. *Strombodes pentagonus*; 2. *Favosites favosus*; 3. *Diphyphyllum multicaule*; 4. *Omphyma verrucosa*; 5. *Halysites catenulatus*; 6. *Halysites catenulatus*, seen from above. All figures, except No. 5, are slightly under half size, and represent specimens from Manitoulin island.

and show a closer relationship to European forms, indicating a migration through Arctic regions. The fossils of the Silurian rocks of the Rocky Mountain area are not numerous: they indicate a fauna derived from Pacific waters.

An outline of the life of Silurian time follows:

PLANTS. In the lower part of the Silurian, as in the Ordovician, no vegetable life of higher organisation than seaweeds

has been found; in the upper part, however, occurs the earliest known terrestrial plant, *Psilophyton,* a very primitive spore-bearing plant discovered by Dr. Dawson in the Silurian rocks of Gaspé.

SPONGES. In Middle Silurian time a type of sponge with very thick walls composed of interlocking spicules of silica makes its appearance in some numbers. On account of the rigid character of the skeleton, these sponges are known as "stony" or "lithistid" sponges: they may be procured in abundance from the cherty layers at the top of the "mountain" at Hamilton, Ontario.

CORALS. Corals are much more abundant than in the Ordovician; in Middle Silurian time they formed great reefs. Fossil hill in Manitoulin island is a famous collecting-ground for these Silurian corals. The remains are enclosed in limestone, but have been converted into silica and weather out on the surface on account of their superior hardness. Common genera are *Halysites* (chain coral), *Favosites* (honey-comb coral), *Diphyphyllum*, *Strombodes,* and *Omphyma*. *Halysites* is the most characteristic fossil of the Silurian rocks of the Rocky mountains, which are called the *Halysites beds* in consequence.

GRAPTOLITES. True graptolites such as characterised the Ordovician are far less abundant in the Silurian strata. There is, however, a strong development of a related type of creature in which the skeleton is a frond-like expansion composed of numerous irregular branches; these are called *dendroid graptolites,* in allusion to their form. They occur in great abundance in the cherty layers of the Lockport formation on the top of the mountain at Hamilton. *Dictyonema* is a common and characteristic example.

FIG. 105. SILURIAN DENDROID GRAPTOLITE

Dictyonema crassibasale from the Silurian at Hamilton, Ont. About one-half size. *After Bassler.*

STROMATOPOROIDS. These are very peculiar creatures, the

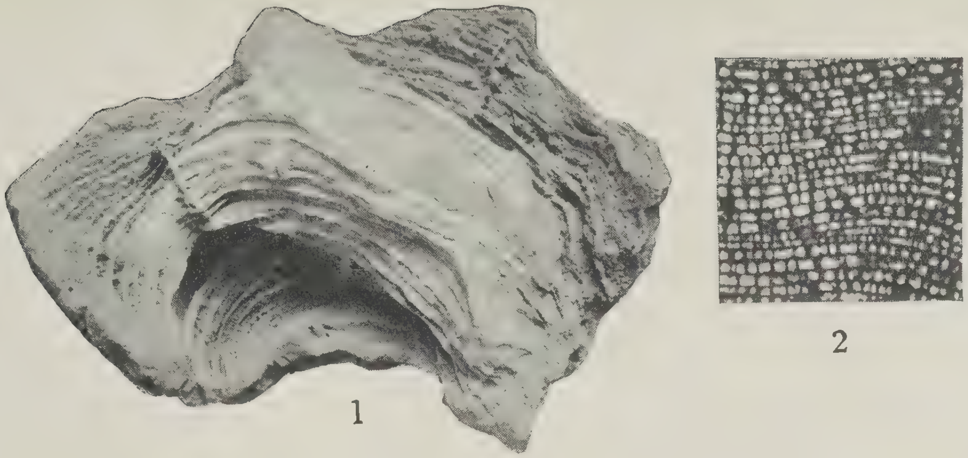

FIG. 106. STROMATOPOROIDS OF THE SILURIAN

1. Weathered specimen of a stromatoporoid showing the concentric laminæ; 2. Vertical section of a stromatoporoid (*Clathrodictyon*) showing the horizontal laminæ and vertical pillars.

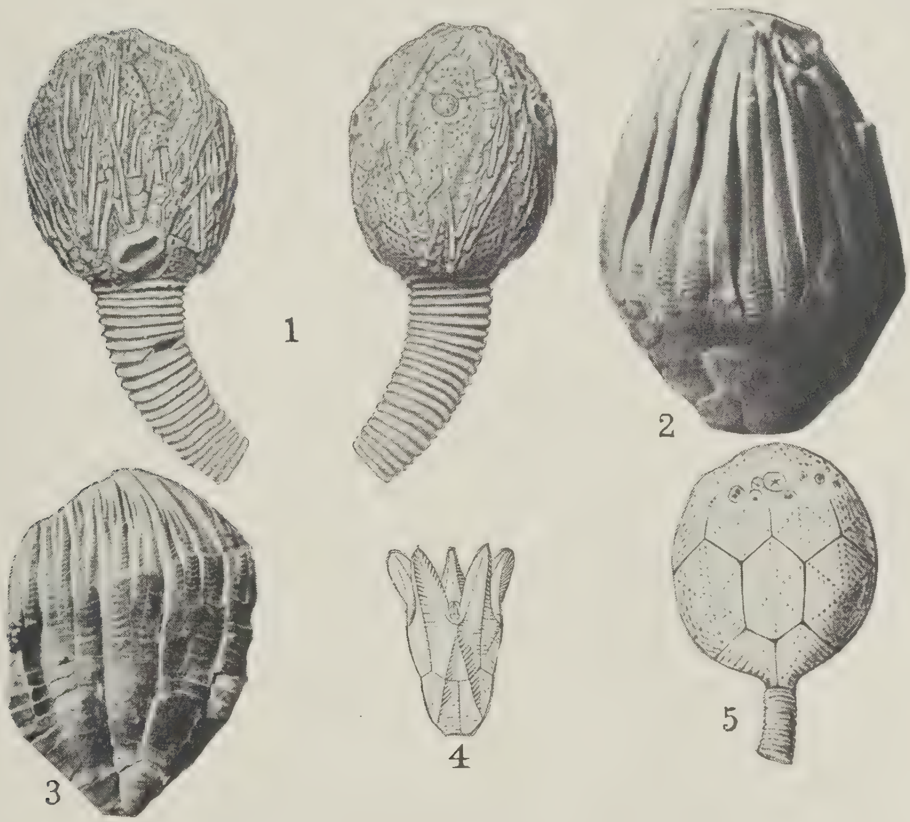

FIG. 107. SILURIAN CRINOIDS AND CYSTIDS

1. *Callocystis jewetti*, a very perfect specimen from the Rochester shale at Grimsby, Ont.; 2. *Eucalyptocrinus cœlatus* ; 3. *Ichthyocrinus lævis* ; 4. *Stephanocrinus angulatus* ; 5. *Caryocrinus ornatus*. All figures seven-eighths natural size.

exact relationships of which are doubtful. The skeletons consist of innumerable delicate laminæ of carbonate of lime placed only a fraction of a millimetre apart and connected by

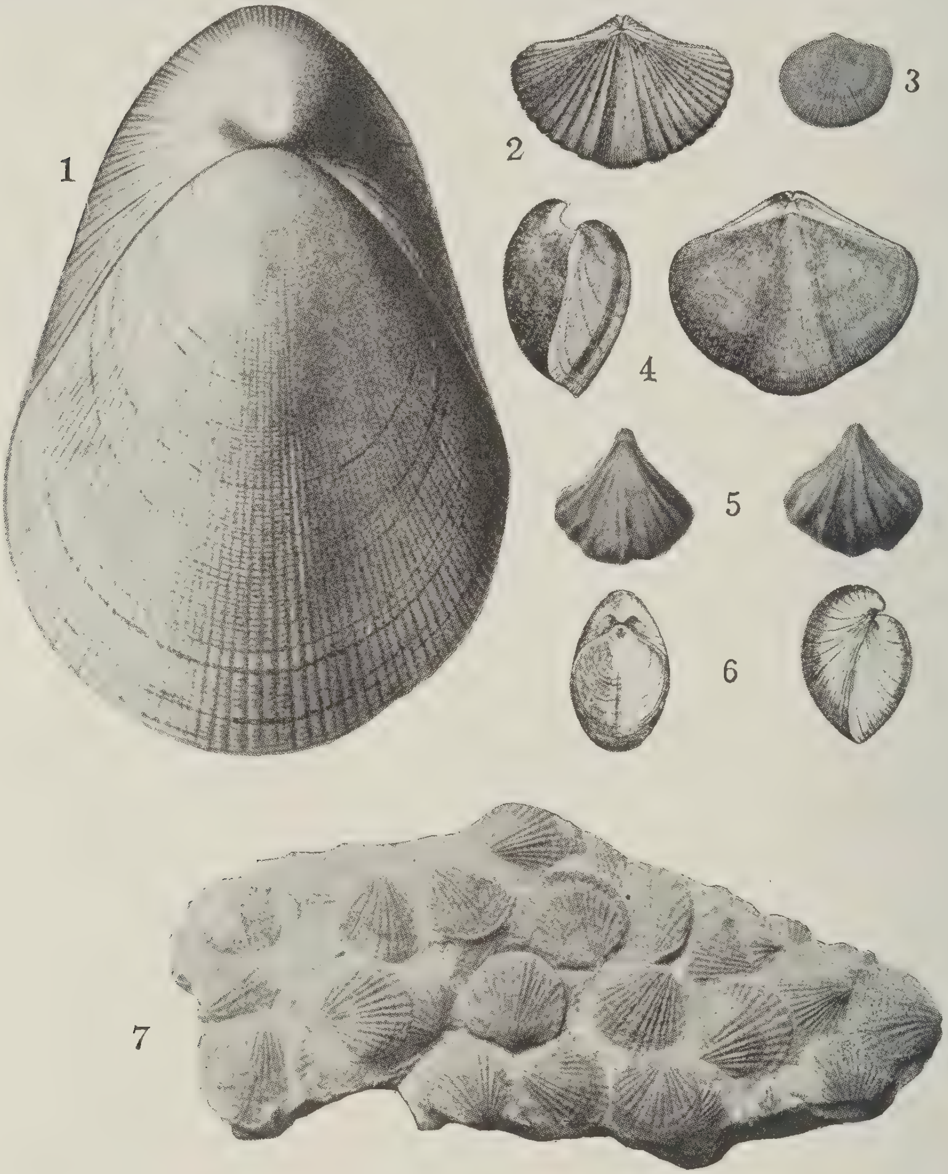

FIG. 108. SILURIAN BRACHIOPODS

1. *Conchidium decussatum*, this large species is common in the Silurian of Manitoba; 2. *Spirifer niagarensis*; 3. *Dalmanella elegantula*; 4. *Spirifer striatus*; 5. *Rhynchotreta cuneata americana*; 6. *Hindella umbonata*; 7. *Cœlospira planoconvexa*. All figures natural size. *After Billings, Whiteaves, Hall, and photos.*

little rods or pillars. In spite of their delicate structure the skeletons reach large dimensions, sometimes feet in diameter; in some places they build up whole beds of limestone.

While stromatoporoids are not unknown in the Ordovician, they first reach a position of importance in Silurian time. The strata of the lower and middle divisions in Ontario contain many species, and whole layers of rock on the Saskatchewan river are composed of their remains. *Stromatopora, Actinostroma,* and *Clathrodictyon* are common genera.

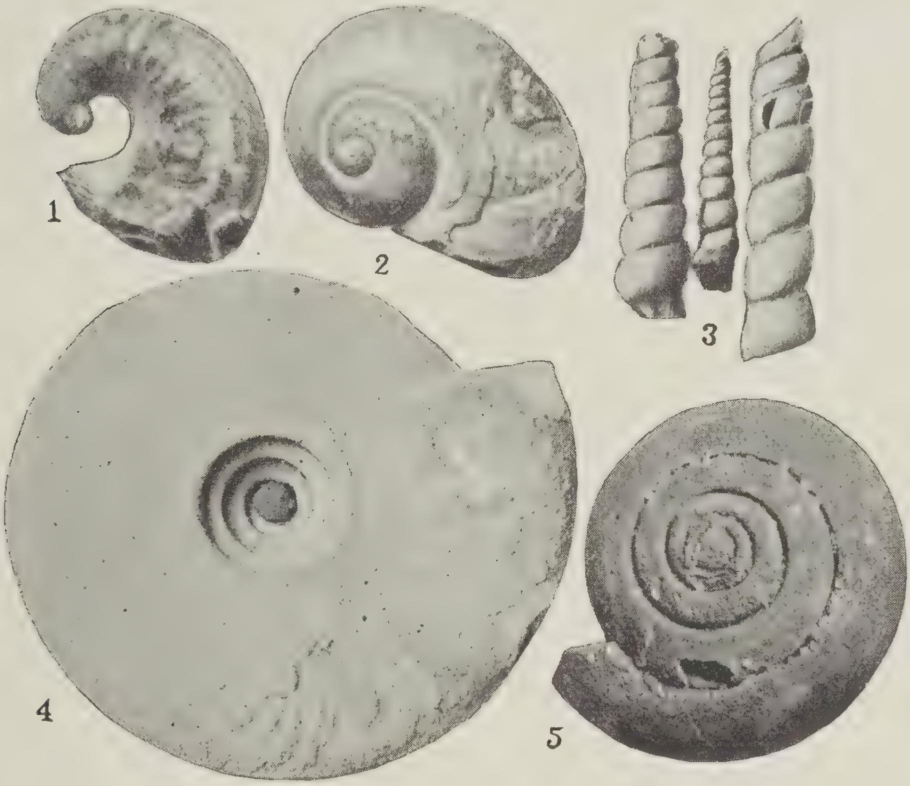

FIG. 109. SILURIAN GASTROPODS

1. *Platyceras niagarense*; 2. *Diaphorostoma niagarense*; 3. Three species of *Cœlocaulus*; 4. *Liospira perlata*; 5. *Pycnomphalus salaroides*. Nos. 1 and 2 about four-fifths natural size. Rochester shale, Grimsby; Nos. 3, 4 and 5 from casts from the Guelph dolomite; No. 3 about one-third natural size; Nos. 4 and 5 about three-fourths natural size.

CYSTIDS. These creatures are less abundant than in the Ordovician, but some highly-developed types still exist. The Rochester shale has yielded some beautifully preserved forms at Grimsby and other points along the Niagara cuesta. *Caryocrinus* and *Callocystis* are typical.

CRINOIDS. Sea lilies are more abundant than in the Ordovician; they occur in great numbers both in Europe and America, but well-preserved specimens are not common in the Canadian

rocks. The best specimens have been obtained from the Rochester shale at Grimsby, and the overlying limestone contains vast numbers of broken fragments. *Stephanocrinus* and *Eucalyptocrinus* are the commonest genera.

BRACHIOPODS. Brachiopods occur in extraordinary numbers

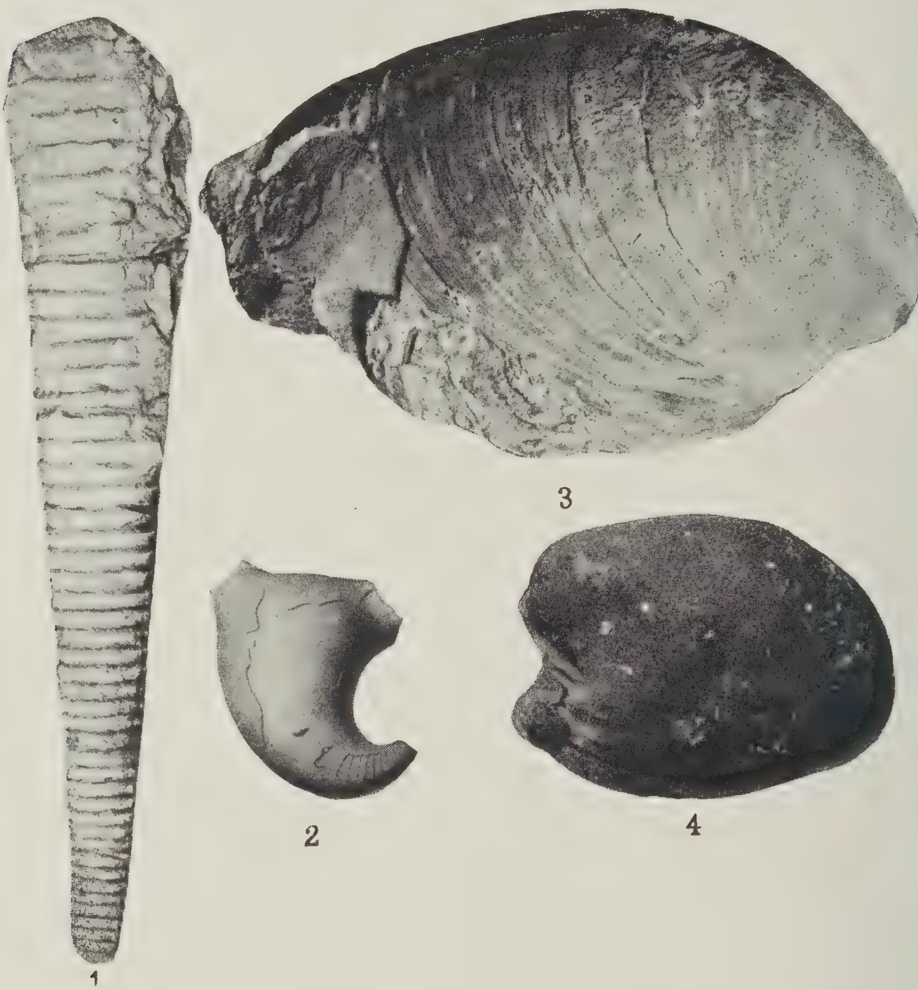

FIG. 110. SILURIAN PELECYPODS AND CEPHALOPODS

1. *Dawsonoceras annulatum*, from a specimen from Ontario; 2. *Phragmoceras lineolatum*, from a specimen from Keewatin; 3. *Megalomus canadensis*, large specimen with shell from the Guelph formation of Ontario; 4. *Megalomus canadensis*, cast of the interior. All figures about three-eighths natural size.

throughout the Silurian, occupying a position scarcely inferior to that which they filled in the Ordovician. The hinged type without arm supports is still dominant, but the more highly developed brachiopod with complicated calcareous loops and spirals for the support of the arms makes its appearance

in some abundance. Of the simpler type, the most characteristic genera are *Dalmanella* and *Rhynchonella*; of the higher type, *Atrypa*, *Cœlospira*, and *Spirifer*.

Gastropods. These forms are increasing in numbers and importance. Ordovician genera such as *Hormotoma*, *Lophospira*, and *Liospira* still survive, and genera of less importance in the Ordovician become very numerous, *e.g.* *Platyceras* and *Diaphorostoma*. The Guelph formation contains a remarkable assemblage of gastropods, many of them belonging to new genera, *e.g.* *Pycnomphalus*.

Pelecypods. The bivalves greatly resemble those of the Ordovician seas: many of the genera are identical, but the species are different. *Megalomus canadensis* is a very large pelecypod characteristic of the Guelph formation, where it occurs in remarkable abundance.

Cephalopods. The nautiloid with straight shell is still abundant and is represented by a number of genera, of which *Dawsonoceras* will serve as an example. Coiled and curved forms are more common than in the Ordovician, *e.g.* *Phragmoceras*.

Trilobites. Trilobites are abundant, but they are somewhat past the supremacy they enjoyed in Cambrian and Ordovician time. The intermediate type is still abundant, but the highest type occurs in increasing numbers. The decline of the trilobites is attributed to the incoming of eurypterids and armoured fish. Examples of the simpler type are *Acidaspis*, *Lichas*, and *Illænus*, and of the higher type *Calymene* and *Dalmanites*.

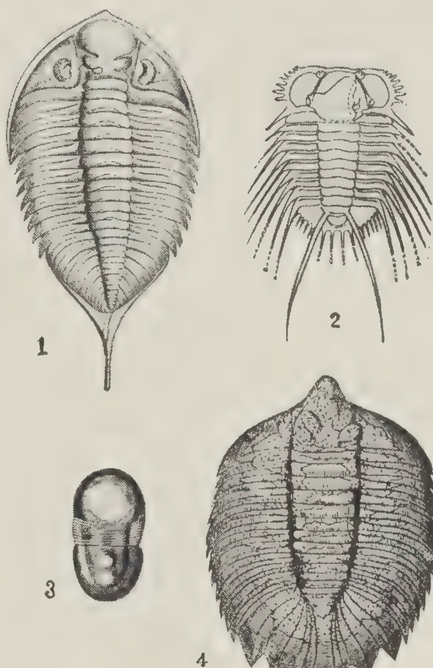

FIG. 111. SILURIAN TRILOBITES

1. *Dalmanites limulurus*, Ontario; 2. *Acidaspis perarmata*, Lake Winnipegosis; 3. *Bumastus barriensis*, a typical European species resembling the American *B. ioxus*; 4. *Lichas boltoni*, a large type, sometimes seven inches in length. Figures much reduced.

Ostracods. These little creatures are still abundant fossils. The Guelph formation of

Ontario shows several species, and they are particularly abundant in the Silurian strata of northern Manitoba.

Eurypterids. These very peculiar organisms are confined to Palæozoic time: they are probably related to the existing king crab, but differ in many important details. The animals were of very general organisation and capable of swimming, crawling on the bottom, or digging in mud, but they were not specialised to perform any of these functions in a very perfect manner. Some of the species were of great size, exceeding a metre in length. They first reach a position of importance toward the close of Silurian time. It is significant that their appearance marks the time of the decline of the trilobites.

FIG. 112. EURYPTERUS REMIPES

About one-eighth natural size. *From Clarke and Ruedemann, "The Eurypterida of New York."*

Fish. Fragmentary remains of fish have been found in Ordovician rocks, but Silurian strata have yielded the earliest fish fauna worthy of the name, as undoubted remains have been found in Europe, Pennsylvania, New York, New Brunswick, and Newfoundland. The fish of this time belong to two types: sharks and the remarkable group known as *Ostracoderms*. The sharks are represented chiefly by the hard granules of the dermal investment and by spines. The ostracoderms are primitive organisms of fish-like appearance and habit. Unlike all existing fish, however, the head and trunk were covered with a thick, hard investment (armour plate), and the creatures were not possessed of jaws. On the latter account some authors place the ostracoderms lower than the fishes and refer them to a separate class, the *Agnatha*.

Silurian ostracoderms were more primitive than those of the next period, and occur in much fewer number. An interesting Canadian example is *Cyathaspis acadica* from the Nerepis hills, King's county, New Brunswick.

Air-breathing invertebrates are represented for the first time by primitive scorpions, *e.g. Palæophonus*, and by insects.

Before the close of the Silurian, as shown above, North America had become more or less clothed with vegetation. *Psilophyton* and other land plants crept over the rocks and

lifted their green stalks a few inches above them. The green of land plants covered what had been the desolation of bare rocks; and the finding of the scorpion and insects just

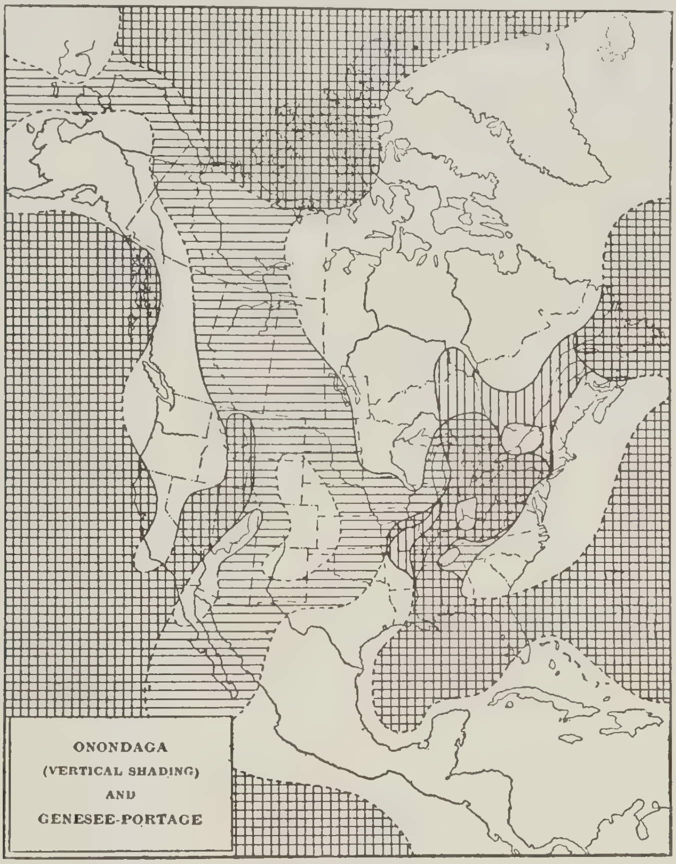

FIG. 113. PALÆOGEOGRAPHIC MAP OF NORTH AMERICA IN MIDDLE AND UPPER DEVONIAN TIME

From Pirrson and Schuchert, "Textbook of Geology."

mentioned is suggestive of air-breathing animals feeding upon the herbage. The earth already had its innocent plant-feeding inhabitants and the predatory creatures that devoured them.

CHAPTER VIII

THE DEVONIAN PERIOD

The name *Devonian* is derived from the type locality in Devonshire where rocks of this system were studied by the great English pioneers of stratigraphic geology, Sedgwick and Murchison. The system as developed in south-western England is much contorted and broken, and its base has not yet been revealed; in consequence, geologists in other parts of the world have great difficulty in correlating their Devonian strata with those of the type locality, and even in drawing the line between the formations of Silurian and of Devonian time. It is, perhaps, a matter of regret that the type region for this great system had not been established elsewhere, where fossils are better preserved and the limits of the system better defined. Such regions are to be found in many parts of the world, *e.g.* in the Rhine valley and in the State of New York, where one of the most complete sequences of Devonian rocks is known.

Before Devonian time diverse facies do not seem to have added greatly to the difficulty of deciphering the history, but in this period there is evidence of two very distinct facies, and from this time on facies becomes a factor to be carefully regarded.

Before the name Devonian was given to the strata of south-western England, a great series of sediments in Scotland had been called the *Old Red*. These strata contain no marine organisms, but they abound in the remains of fishes and plants; they are freshwater deposits, a freshwater facies, whereas the English rocks belong to a marine facies. It is now known that both these facies are of Devonian age; they are recognised in various parts of the world, and are found in Canada.

PHYSICAL EVENTS OF THE DEVONIAN IN NORTH AMERICA

We have seen that emergent conditions prevailed towards the close of Silurian time, with the result that practically

the whole of the present area of North America became land. Devonian time was ushered in by an invasion of the sea into narrow troughs in the Acadian region of Canada, the Appalachian region of the United States, and the Rocky Mountain geosyncline of the west; also, a flood advanced northward from the Gulf of Mexico. This epoch of narrow seas constitutes the Lower Devonian.

A greater subsidence of the continent followed, permitting the union of the waters from the Gulf with those from the Atlantic, and an advance northward of the united flood over a considerable portion of the continental interior. In the Cordilleran area, also, there was a considerable advance of the oceanic waters. This time of maximum depression and flooding is the Middle Devonian.

The later or Upper Devonian epoch saw a gradual elevation of the continent, with a consequent draining away of these seas over the whole of its area.

In the Acadian region, terrestrial movements of a marked kind characterised the Devonian as the land mass was gradually raised and the rocks much folded and twisted. These movements were accompanied by upwellings of molten matter from the interior of the earth and the consequent formation of great granite masses, as at St. George, New Brunswick, and in the Little Megantic mountains and other places in the province of Quebec. Flows of volcanic rock, in all probability of Devonian age, occur in many parts of Nova Scotia and New Brunswick. The remarkable series of isolated mountains, known as the Monteregian hills, which arise abruptly from the Palæozoic plain of western Quebec and stretch from Montreal mountain to Brome mountain, are regarded as the pipes of Devonian volcanoes of which all other evidence has long since disappeared.

THE DEVONIAN SYSTEM IN CANADA

In North America Williams recognises four great provinces of Devonian rocks, each of which carries a fauna of distinctive character which reveals more or less clearly the oceanic basin or basins from which it has been derived. These provinces are:

Eastern Border Province—Maritime provinces and Maine.

Eastern Continental Province—Southern and east central states, the province of Ontario, and the region south of Hudson bay.

Interior Continental Province—Iowa, Minnesota, Illinois, Manitoba, and the Mackenzie River district.

Western Continental Province—Great Basin region, Nevada, etc.

Without regard to faunal provinces, the Devonian rocks of Canada fall naturally into geographical areas as below:

FIG. 114. SKETCH MAP OF EASTERN CANADA SHOWING THE CHIEF AREAS OF DEVONIAN ROCKS

Undoubted Devonian, black; mixed Devonian and Carboniferous, dotted. Other small areas occur in Nova Scotia and New Brunswick, particularly in the northern part of the dotted region in Figure 102.

1. Acadian Area. Narrow and isolated belts of Devonian rocks disposed in a north-east and south-west direction occur at a number of places in Nova Scotia, New Brunswick, and Gaspé. In Nova Scotia, these rocks form an interrupted belt reaching from Minas basin to the Strait of Canso. In Cape Breton, rocks of this system occur near Hawkesbury in Southern Inverness, on Madame island, and at several points in Richmond county.

In New Brunswick, the Devonian strata are confined to small areas in the southern part of the province. A much larger belt extends through the peninsula of Gaspé from its eastern extremity to the Matapedia river. This area is

important, as it presents the best section of the Lower Devonian rocks to be found in Canada. Outliers of this area along Chaleur bay and on the Restigouche river are of Upper Devonian age and continental origin; they are comparable with the Old Red of Scotland, and contain the remains of fish and terrestrial plants.

The Devonian rocks of the Acadian region are sandstones, limestones, shales, and conglomerates; in Nova Scotia and New Brunswick they are much contorted and broken by subsequent earth movements. The strata of the Gaspé area, however, are less disturbed and contain some heavy beds of sandstone suitable for structural purposes.

2. Ontario Area. Devonian rocks form practically the whole of the western peninsula of Ontario west of a line from Fort Erie on Lake Erie to Port Elgin on Lake Huron. The rocks include sandstone, limestone, and shale. The lowest Devonian rocks are not present, as the sea had not advanced into this region until late in Lower Devonian time. The deposits belong, for the most part, to the period of maximum flood in Middle Devonian time. The following table, modified from Stauffer, indicates the formations of the Devonian of Western Ontario.

THE SEQUENCE OF DEVONIAN ROCKS IN ONTARIO

System	Series	Formation	Member
Devonian	Upper Devonian	Portage and Chemung	Port Lampton beds
		Genesee	Huron shale
	Middle Devonian	Hamilton	Ipperwash limestone Petrolia shale Widder beds Olentangy shale
		Delaware	Delaware limestone
		Onondaga	Onondaga limestone Springvale sandstone
	Lower Devonian	Oriskany	Oriskany sandstone

In a general way it may be said that these formations, from the lowest to the highest, are encountered as one passes westward across the area.

The Oriskany sandstone rests unconformably on the Silurian rocks; it is of very limited extent, and is quarried near Cayuga for use as a lining in acid hearth furnaces on account of its highly siliceous character.

The centre of the region is occupied by the Middle Devonian limestones; they are quarried for cement-making, for concrete, and for building. The petroleum of Oil Springs and Petrolia is derived from strata of this age.

The Huron shale of the Upper Devonian series is remarkable on account of containing large spherical concretions of brown calcite, which sometimes reach a diameter of several feet. Kettle point on Lake Huron received its name from the fact that the partially submerged concretions along the shore resemble inverted sugar kettles. The shales are bituminous, and may become a source of oil.

3. James Bay Area. A large area of Devonian rocks occurs in the region immediately south-west of James bay. The fossils resemble those of the Ontario area, and suggest that the rocks were formed in the same sea. In support of the conjecture that the Devonian seas were continuous across the highlands of Ontario, may be mentioned the occurrence of scattered Devonian fossils and even the outcrops of isolated layers of Devonian limestone at different places in the Precambrian region of Northern Ontario, particularly on the Kenogami river, as recorded by Professor Parsons.

Large beds of gypsum are exposed on the Moose river and at other points in the region, and will prove of great value if the country is ever settled.

4. Manitoba-Mackenzie River Area. Devonian rocks pass in a north-westerly direction diagonally across the province of Manitoba, with a width of about 50 miles: Lakes Manitoba and Winnipegosis lie very largely within this belt. After some interruption, owing to covering by later rocks, the system again appears to the north-west, and with gradually increasing width extends nearly to the mouth of the Mackenzie river. An immense area to the south of Great Bear lake and to the west and south of Great Slave lake is

occupied by rocks of this system. As the Devonian strata rest directly on the old Pre-cambrian axis in the northern part of this area, it is evident that the Devonian flood reached wide dimensions in this region. The fossils found in these rocks indicate that the fauna belonged to a sea which did not communicate with that in which the Ontario and James Bay rocks were deposited.

The Devonian rocks of Manitoba are subdivided as follows:

Manitoban.
Winnipegosan.
Elm Point.

The lower or Elm Point formation consists of thin-bedded limestones overlying red shales: the rocks are typically exposed at Elm Point and Steep Rock on Lake Manitoba. The limestones are extensively quarried for cement-making and lime-burning.

The Winnipegosan formation is a highly dolomitic limestone which may be seen to best advantage on the east shore of Dawson bay, Lake Winnipegosis, where it forms steep and picturesque cliffs.

The Manitoban formation is composed largely of almost pure limestone, which is much more heavily bedded than the strata of the Elm Point formation. Cliffs on the west side of Dawson bay, and on Snake island in Lake Winnipegosis, afford numerous fossils characteristic of the formation.

The following classification of the Devonian strata of the Mackenzie River district has recently been published:

	Formation	Correlation
Upper Devonian	Hay River limestone Hay River shales Simpson shales	Chemung Chemung Portage
Middle Devonian	Slave Point limestone Presqu'ile dolomite Pine Point limestone	Manitoban Winnipegosan Elm Point

5. Rocky Mountain Area. Devonian limestones accumulated to a great thickness in the Rocky Mountain geosyncline,

and now form a conspicuous element in the easterly ranges of the mountains. Three formations are recognised as follows:

Lower Banff limestone.
Intermediate limestone.
Sawback limestone.

The Lower Banff limestone is the most conspicuous formation; it is a hard and rather dark limestone with a thickness of 2000 feet in the Rockies of southern Alberta. This formation forms the conspicuous lower knee of the mountain shown in Figure 129. Fossils are few and poorly preserved in the Devonian rocks of the mountains, and our knowledge of the northward extent of the system is very limited. The Cordilleran sea is thought to have been continuous with that in which the Manitoba-Mackenzie River rocks were formed.

LIFE OF THE DEVONIAN

Fossils are extremely abundant in Devonian rocks in all parts of the world; even in Arctic and Antarctic regions, species are found which indicate temperate to sub-tropical conditions. It is a fair conclusion that the climate of Devonian time was genial over the whole earth, a condition very favourable to the development of great numbers of animals, but perhaps not so favourable to the development of new orders.

Devonian life differs from that of the Silurian, not in the introduction of many new groups of organisms, but in the decline of paramount groups of the Silurian and the great development of types which played but a small part in that period. Cystids and graptolites, so characteristic of Silurian and Ordovician time, are practically unknown. Trilobites have seriously declined and brachiopods are somewhat less abundant. On the other hand, terrestrial plants reach a position of great importance; gastropods and pelecypods increase; and there is a development of corals and fish so remarkable that the period has been called *The Age of Corals and Fish.*

While the difference between the life of the two periods consists largely in the relative development of the classes of

organisms, there is, nevertheless, a substantial difference when the two faunas are compared in any detail, as the following brief summary will show:

DEVONIAN PLANTS

The lowly *Psilophyton* of the Silurian was the forerunner of a terrestrial flora which consisted very largely of vascular cryptogams or spore-bearing plants, but some primitive gymnosperms are known as well. As this flora reached a greater development in the period following the Devonian, its consideration will be deferred until the Carboniferous system is taken up.

In Canada, as most of the rocks are of marine origin, the remains of plants are not common. In the Acadian region, however, many species have been found, particularly in the continental Devonian of Gaspé.

FIG. 115. SILURIAN AND DEVONIAN PLANT

Psilophyton princeps, one of the earliest land plants from the Devonian sandstone of Gaspé. Reduced. *After Dawson.*

DEVONIAN INVERTEBRATES

SPONGES. While these organisms are not particularly abundant throughout the system, some of the fine sandy shales of the Upper Devonian in the State of New York have yielded a remarkable number of delicate siliceous sponges, some of which attained a length of a foot or more (*Dictyospongidæ*).

CORALS. Corals reached a wonderful development in the warm Devonian seas and contributed much to the formation of limestone, more particularly where they were segregated into reefs. As corals live at definite depths in the sea, dislike muddy water, and tend to a colonial manner of life, it is not to be expected that all Devonian rocks will show their remains in equal profusion. Many of the shaly members of the system and some of the limestones are entirely without corals.

The genus *Favosites*, already referred to in the description of Silurian life, is represented by a great number of species, and the related genus *Michelinea* (bee's-nest coral) is likewise

abundant. Of the single type of coral, *Cyathophyllum* and *Heliophyllum* are common; while *Diphyphyllum*, *Crepidophyllum*, and *Phillipsaster* are examples of the compound type.

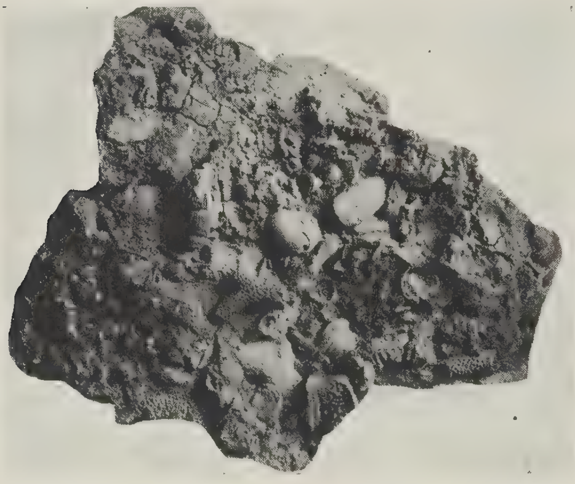

FIG. 116. SLAB OF ONONDAGA LIMESTONE FROM ONTARIO SHOWING THE PROFUSION OF FOSSILS

The Onondaga formation in the vicinity of Port Colborne, Ontario, contains vast numbers of corals which have been converted into silica, and consequently weather out on the surface as the limestone decays. The banks of the Aux Sables river in Lambton county, Ontario, yield fossil corals in an exquisite state of preservation.

Stromatoporoids. These peculiar reef-building organisms form whole layers of limestone of many feet in thickness. Petoskey, Michigan, and Kelly island in Lake Erie are well-known localities for the collecting of stromatoporoids; they are also abundant in the rocks of the James Bay area. These organisms will not be referred to again as they do not survive the Devonian, at least in America.

Echinoderms. Cystids have become so rare that they may be said to be practically extinct. Crinoids are steadily increasing, but they are so similar to the Silurian type that it is difficult to express the difference in general terms. The commonest Canadian genera are *Megistocrinus*, *Dolatocrinus*, and *Arthracantha*.

Blastoids are echinoderms which seem to replace the cystids; although known in lower formations, they first assume a position of importance in the Devonian. Like cystids and crinoids, they are cup-shaped, plated organisms anchored to the sea floor by a jointed stem. The plates of the cup are very regular in arrangement, more so than in crinoids or cystids, from which they also differ by having the food-gathering plumes arranged along the edges of five V-shaped

notches in the upper margin of the cup. *Codaster* is a very primitive blastoid, and is common in the Hamilton strata of the Aux Sables river, Ontario; *Granatocrinus* and *Pentremitidea* are more advanced types from the same locality.

BRYOZOA. These organisms are still very abundant, but the type with long tubular cells is giving place to a short-

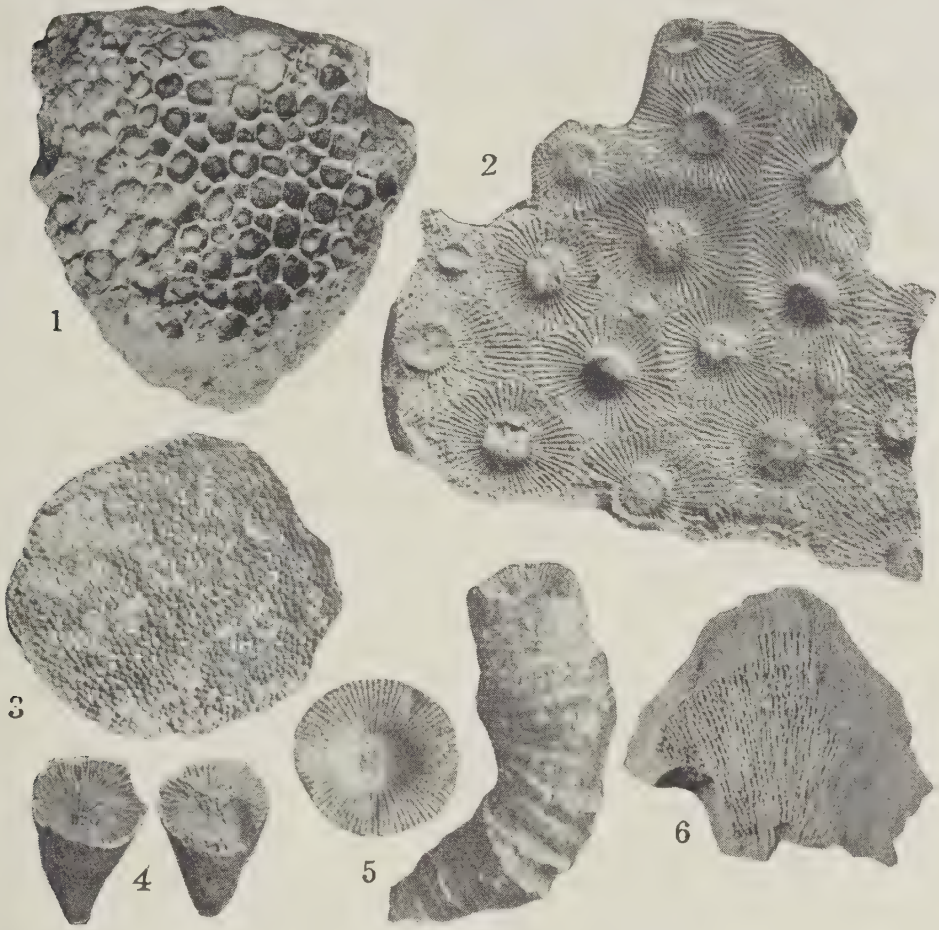

FIG. 117. DEVONIAN CORALS

1. *Michelinea convexa*; 2. *Phillipsaster billingsi*; 3. *Favosites billingsi*; 4. *Streptelasma prolificum*; 5. *Heliophyllum halli*; 6. *Syringopora hisingeri*. All figures about five-sixteenths natural size from specimens from Ontario.

celled kind in which the little individuals inhabit pits which are arranged along the ribs of an open, lace-like frond. The genus *Fenestella*, which first appeared in the Silurian, is represented by a great many species.

BRACHIOPODS. Brachiopods continue to be the most abundant shell-fish, only slightly less in relative importance than in the Ordovician and Silurian.

Many of the Silurian genera have disappeared, while others, *e.g. Spirifer* and *Atrypa,* attain their maximum development. Brachiopods without arm-supports are relatively less abundant, and are represented by such genera as *Stropheodonta* and *Chonetes.* The more highly-developed forms with spiral or looped arm-supports rule in this period—*e.g. Spirifer, Atrypa, Athyris,* and *Cyrtina* with spires, and *Stringocephalus, Centronella,* and *Terebratula* with loops.

FIG. 118. DEVONIAN CRINOIDS AND BLASTOIDS

1 and 2. *Dolatocrinus canadensis*; 3. *Ancyrocrinus bulbosus* (roots); 4. *Arthracantha punctobranchiata*; 5. *Codaster canadensis*; 6 and 7. *Pentremitidea filosa*; 8. *Granatocrinus leda.* Figures 1 to 6 half size, Figures 7 and 8 natural size.

Pelecypods and Gastropods. These molluscs show a steady advance on the position they occupied in Silurian time; the general type, however, is practically the same. Of gastropods, *Diaphorostoma, Euomphalus,* and *Platycerus* are the most abundant; while the pelecypods are represented by *Conocardium, Aviculopecten, Grammysia,* and numerous other genera.

Cephalopods. The nautiloid shells, so characteristic of Ordovician and Silurian time, still occur in abundance, and are represented by the old straight-shelled type, *Orthoceras*; the sack-shaped type with restricted apertures, *Gomphoceras* and *Phragmoceras*; the curved type, *Cyrtoceras*; and the coiled type, *Gigantoceras* and *Centroceras.*

In addition to the cephalopods of this kind, there occurs for the first time a new type which is destined to replace the nautiloids and to become the dominant creature of a later era. The nautiloid shell has been described on page 213; the new cephalopod differs in that the suture, or line of union between the partitions and the shell proper, is not simple as in the nautiloids, but angulated and folded. The primitive forms of the new type, as seen in the Devonian, show a comparatively simple angulation of the sutures and are known as *clymenoids.*

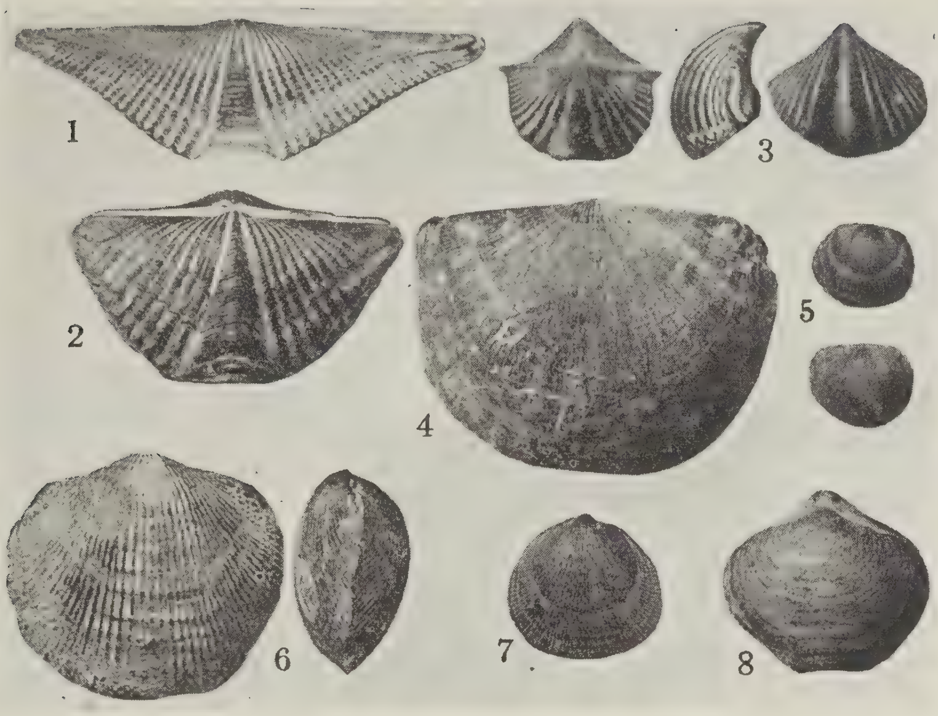

FIG. 119. DEVONIAN BRACHIOPODS

1. *Spirifer pennatus arkonensis*; 2. *Spirifer pennatus thedfordensis*; 3. *Cyrtina hamiltonensis*; 4. *Stropheodonta inæquistriata*; 5. *Chonetes coronatus*; 6. *Atrypa reticularis*; 7. *Rhipidomella vanuxemi*; 8. *Athyris spiriferoides*. All figures seven-eighths natural size, from specimens from Ontario.

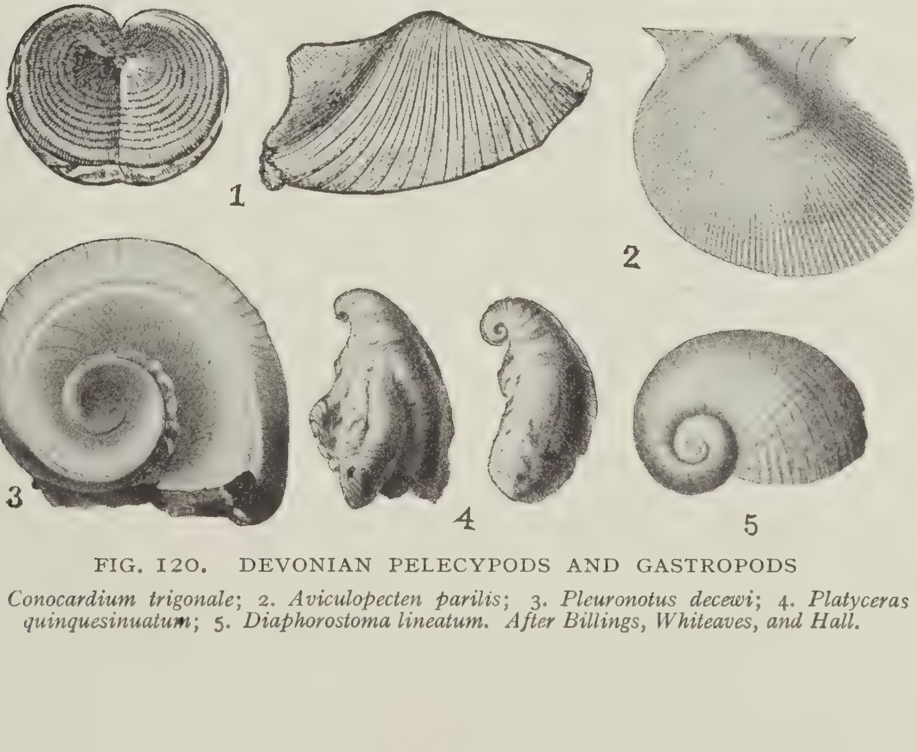

FIG. 120. DEVONIAN PELECYPODS AND GASTROPODS

1. *Conocardium trigonale*; 2. *Aviculopecten parilis*; 3. *Pleuronotus decewi*; 4. *Platyceras quinquesinuatum*; 5. *Diaphorostoma lineatum*. *After Billings, Whiteaves, and Hall.*

TRILOBITES. The trilobites show a marked decline in the Devonian; nevertheless, many new species appear which belong for the most part to genera already introduced in

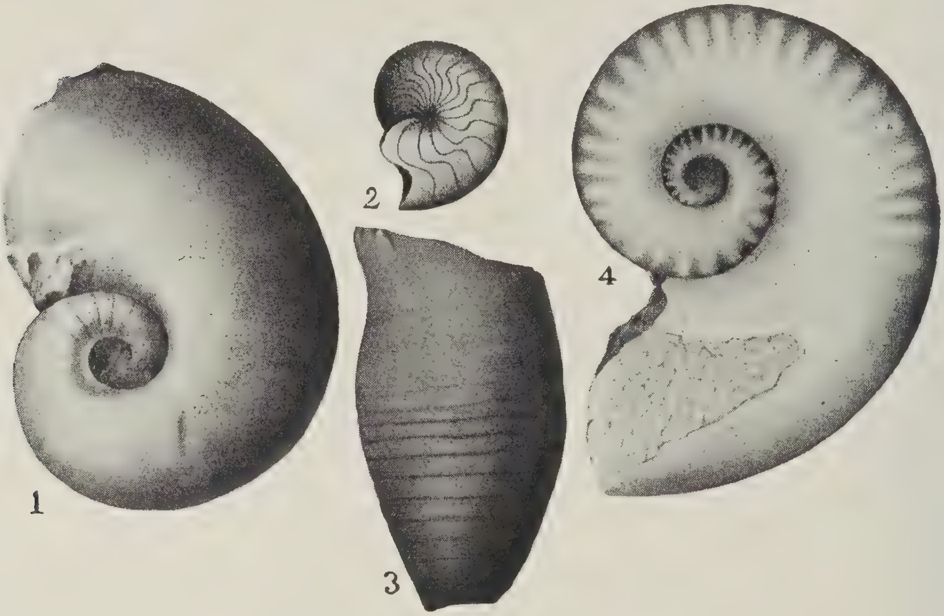

FIG. 121. DEVONIAN CEPHALOPODS

1. *Gigantoceras inelegans*; 2. *Tornoceras uniangulare*; 3. *Poterioceras eximium*; 4. *Centroceras ohioense.* All figures much reduced. *After Hall.*

the Silurian. Common examples are *Phacops*, *Proëtus*, and *Dalmanites.*

EURYPTERIDS are still abundant; the higher crustaceans are increasing, and terrestrial air-breathing invertebrates are much more prominent than in the earlier periods.

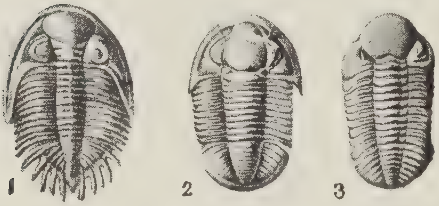

FIG. 122. DEVONIAN TRILOBITES

1. *Cryphæus boothi*; 2. *Proëtus rowi*; 3. *Phacops rana.* Half size. *After Hall.*

INSECTS. Insects like our mayflies are known from near St. John, N.B., *Platyphemera antiqua*, with a five-inch spread of wing. Dr. Scudder thinks that one insect, *Xenoneura antiquorum*, was possessed of a chirping organ.

DEVONIAN VERTEBRATES

FISH. Fish made their first appearance in the Ordovician period, and reached but a feeble development in the Silurian; in the Devonian, however, they attained a position of great importance. Remains of fishes are extremely abundant in the Old Red Sandstone of Scotland, and many examples are known from the deposits of similar facies in the Acadian region of Canada. The truly marine Devonian also has furnished fossil fishes in both Ontario and Manitoba.

The different types of fish represented in Devonian time are briefly described below:

Ostracoderms. Jawless, fish-like organisms, without paired

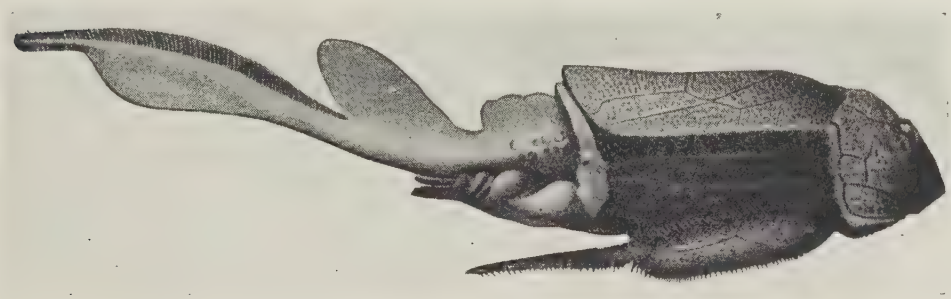

FIG. 123. TYPICAL DEVONIAN OSTRACODERM

Bothriolepis canadensis. Much reduced. *After Patten.*

fins, and with the head and anterior portion of the trunk covered with plates. *Cephalaspis* has a large triangular head shield, and the body is covered with quadrangular scales. Five species are known from New Brunswick and Quebec. *Bothriolepis canadensis* is a more highly developed ostracoderm from Scaumenac bay, Quebec; in this fossil there are separate head and body shields each composed of a number of plates, also a pair of pectoral fins or "rowing arms" likewise covered with plates and articulated to the angles of the head shield. This remarkable organism is closely related to the better known *Pterichthys*, of which many species are known in different parts of the world.

Sharks. Using this term in the widest sense, the Devonian period presents a great number of different types, some of which are known only by teeth or spines, while others are

preserved in a manner to show the whole outline of the animal. *Cladoselache* is a very primitive form from the Devonian rocks of Ohio, and *Pleuracanthus* is likewise a simple form which is not known in Canada, although teeth of related genera are found in New Brunswick. Small spiny fish known as *acanthodians* are represented by eight species in the Devonian rocks of Quebec and New Brunswick. The presence of large, shark-like fish is attested by the presence of spines known as *ichthyodorulites*, of which *Machæracanthus* will serve as a Canadian example.

Lung-fishes. These peculiar fish, in which the air bladder is modified into a breathing organ (lung), are of rare occurrence at the present time, but in the Devonian period they

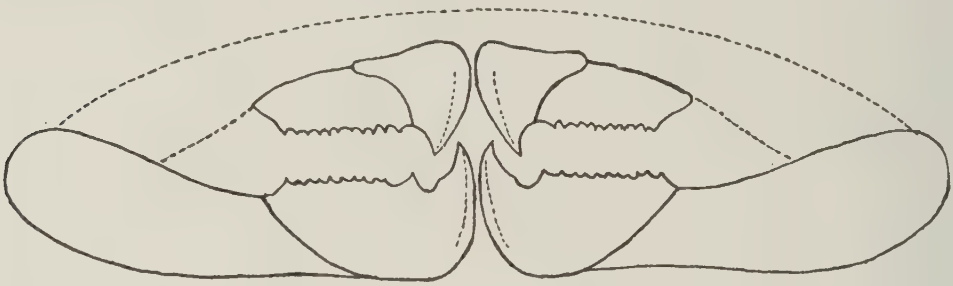

FIG. 124. JAWS OF THE "TERRIBLE FISH"

Dinichthys hertzeri, from the Devonian shales of Ohio. Much reduced. *After Newberry.*

seem to have played a very important rôle. *Scaumenacia curta* is the best known Canadian example, from the famous region of Scaumenac bay, Quebec. A peculiar group of fish, probably related to the lung-fishes, is the *Arthrodira*, in which the head and trunk are protected by thick plates, as in the ostracoderms. Some of these fish reached extraordinary dimensions, *e.g. Dinichthys* measured more than a metre across the head. *Coccosteus* from Quebec, *Macropetalichthys* from Ontario, and *Dinichthys* from Manitoba are the best known Canadian examples.

Ganoids. Although the line of separation between the ganoids and the true bony fish, or teleosts, is very indistinctly marked, a ganoid may be distinguished by the possession of a cartilaginous skeleton and thick rhomboidal scales, instead of the bony skeleton and thin flexible scales of the teleost. The most primitive ganoids, the *Crossopterygii*, were parti-

cularly abundant in and characteristic of Devonian time. These fish possessed "fringed fins," *i.e.* the fin had a central

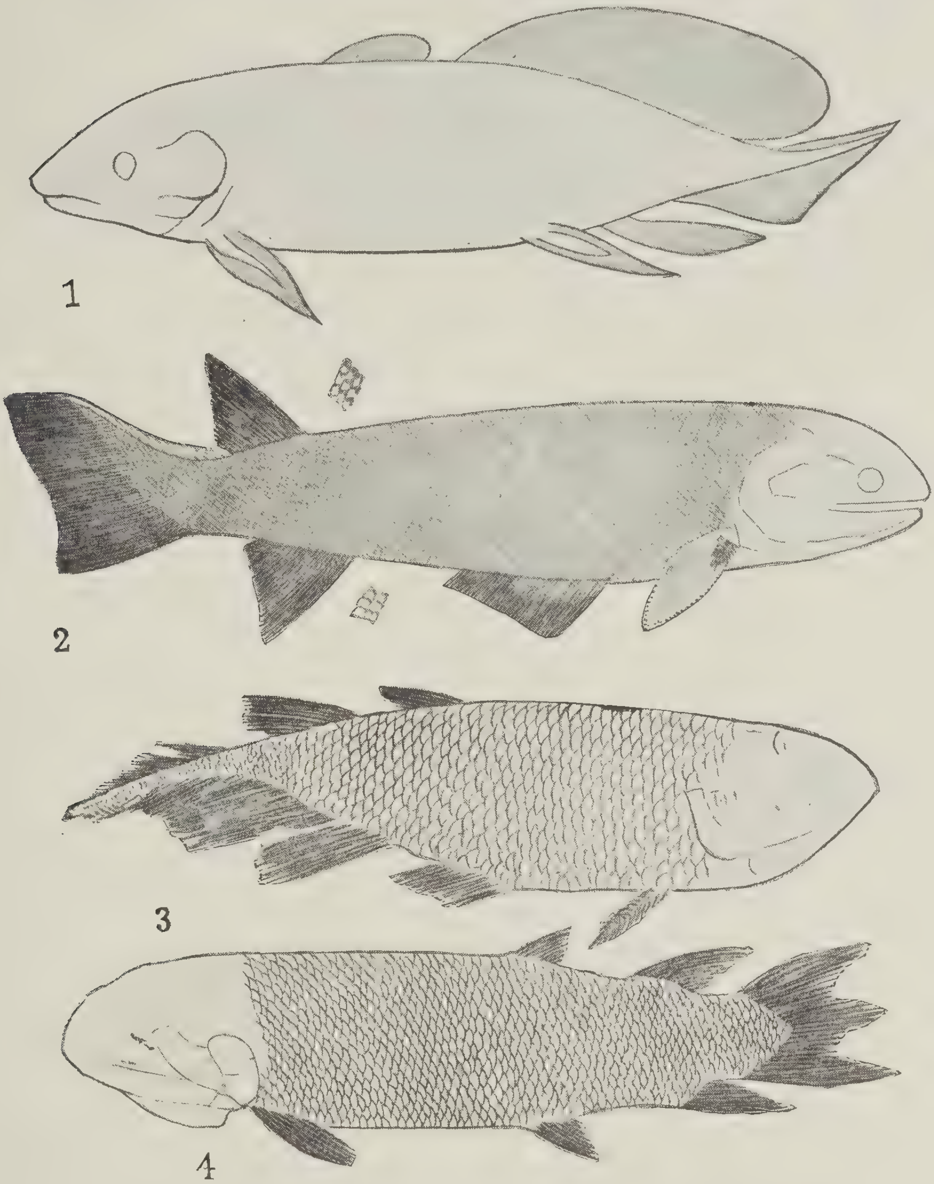

FIG. 125. DEVONIAN FISH

1. *Scaumenacia curta*, Canadian lung-fish; 2. *Cheirolepis canadensis*, Canadian heterocerca ganoid fish; 3. *Holoptychius quebecensis*, Canadian fringe-finned ganoid; 4. *Eusthenopteron foordi*, Canadian fringe-finned ganoid. Figures 1 and 2 about one-fourth natural size, Figures 3 and 4 about three-eighths natural size. *After Traquair and Whiteaves.*

axis from which the fin-rays sprang out on two sides, and the joints of the backbone continued to the tip of the tail (diphycercal). *Holoptychius*, a stout fish of two feet or more

in length, is the best known example, and is represented by *Holoptychius quebecensis* from Scaumenac bay.

The heterocercal ganoids, in which the paired fins have no scaly axis, and in which the termination of the vertebral column turns up into the dorsal lobe of the caudal fin, are of less frequent occurrence than the crossopterygian fish; nevertheless, they begin their existence in Devonian time and reach a remarkable development later. *Cheirolepis canadensis* is the only Canadian example.

FIG. 126. DEVONIAN OSTRACODERM

Head shield of the armoured fish, *Cephalaspis campbelltonensis*. About one-third natural size.

The Devonian fish fauna is remarkable on account of its rapid development, the variety of forms represented, the bizarre shape of many of its members and the size and ferocity of others, its coincidence with the decline of the trilobites, and the evidence it affords of the futility of armour, as none of the plated fish survive the Devonian period.

AMPHIBIA. The higher air-breathing vertebrates seem to have made a beginning in the Devonian, but the evidence is not very extensive. A single footprint from the Upper

FIG. 127. KETTLE POINT, LAKE HURON

Port Huron shales with concretions of carbonate of lime.

Devonian of western Pennsylvania is thought to attest the presence of a forerunner of the amphibians of the next great period.

On the land great advances took place during the Devonian; the creeping club mosses had aspired to become trees, and in Eastern Canada there seem to have been the stiff uncouth beginnings of forests. Air-breathing animals, too, had progressed so far that numerous insects flitted among the trees: these creatures probably possessed chirping organs; the country was no longer voiceless.

CHAPTER IX

THE CARBONIFEROUS PERIOD

THE closing stages of the Palæozoic era were marked by such varying conditions in different parts of the world that the strata are with difficulty arranged in correlated groups or even in comparable systems for the different continents. European geologists recognise two great systems, the Carboniferous and the Permian. In India, South Africa, and Australia, while true Carboniferous rocks are recognised, the upper or Permian system is so ill defined that the term Permo-Carboniferous is adopted for the later rocks. In North America the lower strata are so well developed in the Mississippi valley, and so sharply marked off from the overlying rocks, that they are thought to represent a great system in themselves: this system is known as the *Mississippian*, and is comparable with the Lower Carboniferous of European geologists. The rocks above the Mississippian likewise form a very distinct unit and are embraced in a great system, the *Pennsylvanian*, by American geologists. The highest strata of all, which one would expect to correlate with the Permian of Europe, are so feebly developed and fade so imperceptibly into the underlying Pennsylvanian rocks that they may be included in that system.

CORRELATION TABLE OF THE CARBONIFEROUS AND PERMIAN OF EUROPE AND NORTH AMERICA

<table>
<tr><th colspan="2">EUROPE</th><th>NORTH AMERICA</th></tr>
<tr><th>System</th><th>Series</th><th>System</th></tr>
<tr><td rowspan="2">Permian</td><td rowspan="2"></td><td>Permian</td></tr>
<tr><td rowspan="2">Pennsylvanian</td></tr>
<tr><td rowspan="2">Carboniferous</td><td>Upper Carboniferous</td></tr>
<tr><td>Lower Carboniferous</td><td>Mississippian</td></tr>
</table>

The great terrestrial movements which have determined the definition of systems in North America have naturally affected Canada as well as the United States; therefore, it would seem to be advisable to adopt the nomenclature of the geologists of the United States. On the other hand, it does not seem advisable to leave out of the literature the old term Carboniferous in an elementary work intended to give a general survey of geological history.

The term Carboniferous owes its origin to the fact that the strata contain a great amount of carbon in the form of beds of coal. The practice of naming systems or formations according to the kind of rock was quite common in the early days of the science, but it has been abandoned in favour of the use of geographic terms. European geologists recognise two subdivisions of the Carboniferous system, a lower series with predominating limestones representing sedimentation in a deep sea, and an upper series which carries the coal and is consequently known as the "Coal Measures."

PHYSICAL EVENTS OF THE CARBONIFEROUS IN NORTH AMERICA

The advancing seas of early Carboniferous time invaded a continent which had largely emerged by the close of the Devonian period. These waters extended northward from the Gulf of Mexico, and gradually spread over a great area in the region of the Mississippi river and northward into Michigan, Ohio, and Pennsylvania. At the same time the Rocky Mountain geosyncline was flooded, probably into Arctic regions, and fossils entombed which suggest a connection between the Cordilleran and mid-continental basins. A third limited area of invasion was in the Acadian region of Canada, where the seas advanced over upturned Devonian rocks, on which their deposits now rest with pronounced unconformity. The fossils from this area are very different from those of the mid-continental and Cordilleran regions, and indicate that there was no communication across the Alleghanian highlands. A retreat of the sea, abrupt in the Cordilleran region but more gradual in the mid-continental

region, brought the Mississippian or Lower Carboniferous epoch to a close.

Upper Carboniferous (Pennsylvanian) time was marked in eastern North America by slight crustal movements and shallow invasions of the seas into more or less land-locked basins, wherein were deposited the great accumulations of vegetable matter which have subsequently become coal.

Greater terrestrial movements affected the Pacific border of the continent in the Upper Carboniferous epoch. The seas advanced for the first time on the western flank of the old land, which throughout long ages had existed to the westward of the Rocky Mountain geosyncline. The deposits of this sea are distinctly marine, and they never contain coal; on the other hand, the sedimentary rocks are frequently mingled with volcanics, indicating a state of great unrest in the terrestrial crust of this area.

COAL

Accumulations of vegetable matter, buried in the rocks and subsequently subjected to the pressure exerted by the overlying rocks or by crustal movements, are altered into coal. It is apparent that the character of the coal will vary with the degree to which these forces have acted: if the pressure is slight and the duration of action not too long, the resulting coal will be woody and the gaseous constituents of the original matter will be expelled to a minimum degree. On the other hand, heavy forces acting for a long time will so alter the original matter that it will be reduced to the condition of carbon, and the gaseous constituents will be largely expelled. Between these extremes lie all possible stages in the gradual transformation of woody matter into coal.

The more important constituents of coal are carbon (uncombined or fixed carbon), volatile matter, ash, and water. The relative percentages of these ingredients determine, to a very large extent, the commercial classification of coals. The varieties more commonly recognised are as follows:

Lignite. The least altered type, with low fixed carbon and

water up to 20 per cent. They are soft, are liable to disintegration, and are of relatively low heating power.

SUB-BITUMINOUS. Coals with low percentage of fixed carbon and 6 per cent. or more water. They are intermediate between lignites and bituminous coals.

BITUMINOUS. Coals with 12 to 35 per cent. of volatile matter are sometimes called *humic* or *soft* coals. They contain much volatile matter, and consequently burn readily with pronounced flames. When coals of this class burn without a tendency to fuse together they are called *non-coking*; when they exhibit this property they are *coking* coals, and are valuable for the making of coke. Cannel coal is a highly gaseous type of fine grain and dull lustre; it is used for gas-making and for domestic heating in grates.

SEMI-ANTHRACITE. Coals with 7 to 12 per cent. of volatile matter. They are non-coking and burn freely and quickly with the production of yellow flames and intense heat; in consequence, they are of particular value for the rapid raising of steam and for use in forges.

ANTHRACITE. Hard coal with 3 to 5 per cent. of volatile matter. Anthracite burns with an intense heat and scarcely any flame: it is comparatively clean to handle and produces a minimum of sooty gases, and in consequence is highly desirable for domestic use.

Accumulations of vegetable matter of sufficient extent eventually to make beds of coal have been formed during many of the geological periods from the Devonian onward. In Upper Carboniferous time, however, these accumulations were so much greater than in any other epoch that the bulk of the world's supply of coal is obtained from strata of this age. The strata containing the beds of coal were called the "Coal Measures" by the early geologists, and the term is still used, but not commonly, as a formational name. The Coal Measures consist of layers of sandstone, shale, and coal with a minimum of limestone. As marine fossils are seldom, if ever, found in the measures, we must conclude that the vegetable matter accumulated in freshwater marshes or in marshes originally salt, but which became brackish and eventually fresh by the cutting off of communication with the open sea.

The underclay beneath the coal beds frequently shows the

roots of trees, and erect trunks have been found in many places, *e.g.* at the South Joggins, Nova Scotia. It is concluded, therefore, that the coal-forming plants grew *in situ*, although there is evidence that in some cases the vegetable matter had been drifted into the position in which the coal is found.

The occurrence in the same section of numerous beds of coal separated by layers of sandstone and shale bears witness to the oscillatory character of the waters; and the presence of beds of coal, sometimes many feet in thickness, can be accounted for only on the assumption of a gradually sinking bottom.

THE CARBONIFEROUS SYSTEM IN CANADA

Carboniferous rocks occur only in the extreme east and the extreme west of the Dominion; three general areas may be recognised as below:

1. Acadian Area. Carboniferous rocks occupy a large triangular district of about 10,000 square miles in the province of New Brunswick, and form a somewhat broken belt across the province of Nova Scotia from the Bay of Fundy to Sydney harbour in Cape Breton. Across Cabot strait beds of this age reappear on the western side of Newfoundland.

The Carboniferous rocks of this area are classified as follows:

SUBDIVISIONS OF THE CARBONIFEROUS ROCKS IN EASTERN CANADA

System	Series	Formation
Carboniferous	Upper Carboniferous	Coal Measures
		Millstone Grit
	Lower Carboniferous	Windsor (local) Other local formations

The Lower Carboniferous rocks are coarse clastics indicating rapid deposition, limestone with the fossils characteristic of the time, and beds of gypsum which are extensively mined in both provinces.

The Albert shale, a formation of Lower Carboniferous or, possibly, Devonian age, in New Brunswick is so strongly impregnated with hydrocarbons that oil and ammonium sulphate may be obtained in commercial quantities by distillation. Layers of sandstone associated with these shales yield both petroleum and natural gas. The production of petroleum is small, but natural gas is supplied to Moncton, Hillsboro, and other places. The output in 1913 was 800,000,000 cubic feet, but in 1915 it had fallen to 430,000,000 cubic feet. The natural alteration of seepages of petroleum from the Albert shale has resulted in the formation of veins of a black shining mineral called *albertite*. This substance was mined for more than thirty years and employed as a high-grade gas coal: the supply is apparently exhausted.

FIG. 128. SKETCH MAP OF EASTERN CANADA SHOWING THE EXTENT OF CARBONIFEROUS ROCKS

Lower Carboniferous, dotted; Upper Carboniferous, black; Permo-Carboniferous, vertically lined.

The Millstone grit is of wide extent, and constitutes nearly all of the large district in New Brunswick. The rocks are chiefly sandstones, suitable for building and for the making of grindstones and pulpstones. The strata are conformable with the overlying Coal Measures, and contain thin seams of coal which are worked to a limited extent in New Brunswick.

The Coal Measures consist of alternating beds of shale and coal mingled with sandstones similar to those of the Millstone grit.

Coal-mining in Nova Scotia is one of the most important industries in Canada: more than 65,000,000 metric tons have

been mined, and it is estimated that the coal fields contain a reserve of 7,500,000,000 tons capable of being worked. The coal is of the bituminous type, with the variety cannel coal

FIG. 129. ROCKY MOUNTAINS NEAR BANFF, ALBERTA

The lower knee to the left is the Lower Banff limestone; the darker, more sloping section above is the Lower Banff shale; the upper knee is the Upper Banff limestone covered by the Rocky Mountain quartzite at the top. *Mines Branch, Dept. of Mines, Canada.*

in limited amount. The following table indicates the chief productive regions:

THE COAL FIELDS OF NOVA SCOTIA

Coal Field	Subdivision
Cumberland	Joggins Springhill
Pictou	Westville Stellarton Vale
Inverness	Port Hood Mabou Broad Cove
Sydney	Cape Dauphin Glace Bay Victoria-Lingan Sydney Mines

2. Rocky Mountain Area. The great Rocky Mountain geosyncline continued to be an area of deposition during the Carboniferous; in consequence, strata of this age are found to a great thickness in the mountains of British Columbia and Alberta. The rocks extend far to the north, but their exact limits have not yet been ascertained. The great ranges of the Eastern Rockies overlooking the plains are capped by Carboniferous rocks of which three formations are clearly shown, at least in the southern part of the ranges. Near the line of the Canadian Pacific Railway these formations are as follows:

CARBONIFEROUS FORMATIONS OF THE SOUTHERN ROCKIES

Series	Formation	Thickness	Rocks
Upper Carboniferous	Rocky Mountain Quartzite	800 feet	Hard, white quartzite
	Upper Banff Limestone	2300 feet	Hard, compact limestone, cherty in places
Lower Carboniferous	Lower Banff Shale	1200 feet	Hard, dark-coloured shale

The difference in hardness of the limestone, shale, and quartzite gives the formations a clear definition on the cliff-face of the mountains. The superior hardness of the Rocky Mountain quartzite causes it to form the summits of the ranges, as all the later and softer rocks which originally overlaid it have been removed by erosion.

The Rocky Mountain quartzite contains certain beds carrying a small amount of phosphoric acid. These have been suggested as a source of phosphorus, but they have not yet been proved to be of economic value.

3. Western British Columbia and Pacific Coast Area. In Upper Carboniferous time the lands which had existed for long ages in western British Columbia sank beneath the waters of the Pacific ocean, and strata of this age were deposited over very large areas to a thickness, in places, of at least 9500 feet. The formation has been called

the Cache Creek group, and consists of a lower series of shaly rocks and an upper series of limestone. Volcanic activity was pronounced, and igneous rocks, both effusive and fragmental, are mingled with the sedimentaries. The actual areas covered by these rocks can scarcely be indicated, as they have been much eroded and hidden by later rocks both igneous and sedimentary.

LIFE OF THE CARBONIFEROUS

CARBONIFEROUS PLANTS

The Carboniferous flora consists essentially of vascular cryptogams, with an admixture of primitive seed-bearing plants. The cryptogams were undoubtedly the chief coal-forming plants, as they lived in the low marshes so characteristic of the period. The seed-bearing plants likewise contributed to the making of coal, as their remains are found together with those of the cryptogams.

FIG. 130. CARBONIFEROUS FERNS AND CYCAS-FERNS

A. *Odontopteris subcuneata*; B. *Neuropteris cordata*; C. *Elethopteris longhitica*; D. *Dictyopteris obliqua*; E. *Phyllopteris antiqua*; E′. Natural size (of E); F. *Neuropteris cyclopteroides*. Species from eastern Canada. *From Dawson, "Acadian Geology."*

The vascular cryptogams, or *Pteridophyta*, were represented by ferns, tree-ferns, calamites, sigillarias, and lepidodendrons. The great importance of each of these plants justifies a brief description.

Impressions of leaves very like those of modern ferns have been found in great numbers in the Coal Measures. Until quite recently these leaves were believed to represent true ferns; it is now known, however, that some of them bore seeds, and therefore are to be considered as gymnosperms. Palæobotanists suspect that others of these fern-like plants, in which seeds have not actually been found, are likewise to be ascribed to the gymnosperms.

The fern-like leaves, therefore, belong either to ferns proper or to fern-like plants actually or probably bearing true seeds, and known by the very appropriate name *Cycadofiliacales*, or *cycas-ferns*, in allusion to their intermediate position between the ferns and the lowest gymnosperms, the cycads. *Hymenophyllites* from the eastern coal fields is probably a true fern: the cycas-ferns will be considered under the gymnosperms.

FIG. 131. CARBONIFEROUS TREE-FERNS

Giant ferns with leaves supported on a trunk like a tree were of common occurrence in the forests of both Devonian and Carboniferous time. They are known as tree-ferns, and are represented by *Psaronius* and several other genera from our rocks.

Calamites are very closely allied to the common horsetail, which may be found growing on wet, sandy soil to a height of about eighteen inches in many parts of Canada. The calamites, however, reached the dimensions of trees, with a diameter up to fifteen inches, and had a large central pith surrounded by an external zone of woody tissue. Narrow vertical fluting is characteristic of both the inside and the outside of this woody cylinder. At irregular intervals the continuity of the fluting is interrupted by "nodes," from which arise whorls of limbs. A great many species of calamites are known: Dawson records nine from the coal fields of Nova Scotia alone.

In addition to the calamites which have been determined from stems, a considerable number of related forms have been identified from foliage, *e.g. Asterophyllites* and *Annularia*.

The sigillarias were trees that grew to a height of 100 feet or more, and played an important part in the formation of coal beds. They were evergreen, spore-bearing trees, remarkable in having two kinds of spores, some very large and others very small. The trunk was rather ungraceful, with a diameter as great as six feet at the base; it terminated in a blunt point, and very rarely bifurcated or branched. Leaves

sprang in a regular manner from the whole surface of the tree, but with advancing age and size the lower leaves fell off, leaving scars on the bark. As these scars resemble seals, the plant has been called the "seal-tree" or *Sigillaria* (*sigilla*, a seal). The bark was marked by pronounced fluting, with the leaf-scars arranged in parallel rows down the trunk. Botanically, the plant is related to the existing lycopods.

Lepidodendron resembles *Sigillaria* in many ways, and like it is related to the lycopods as represented by the existing club mosses and ground-pines of our woods. The trees were tall and graceful, with slender, gradually tapering trunks and branches which arose by regular bifurcation. The leaves,

FIG. 132. CARBONIFEROUS TREES

1. Bark of *Sigillaria*; 2. Bark of *Lepidodendron*.

generally small and elongated, sprang from the whole surface as in *Sigillaria*, and left scars in a similar manner. The bark was not fluted as in *Sigillaria*, and the large, diamond-shaped scars instead of being in vertical rows were arranged in a spiral manner around the stem. The smaller branches bore cone-like structures at their extremities, from which enormous numbers of spores were produced.

Many species of both *Lepidodendron* and *Sigillaria* are known from the Carboniferous rocks of eastern Canada; also, in the under-clay are found numerous roots, to which the name *Stigmaria* is given.

The gymnosperms are represented by the *Cycadofiliacales*, already referred to, and the *Cordaitales*, which show relationships to the conifers.

The Cycadofiliacales are well represented in the coal fields of Nova Scotia: common examples are *Alethopteris*, *Neuropteris*, and *Sphenopteris*. The "fern-ledges" near St. John, N.B., have also yielded a large number of similar forms.

The Cordaitales were the most important gymnosperms in Carboniferous time, and they may be considered as the dominant type of gymnosperm in the Palæozoic era. These trees are related on the one hand to the cycads and on the other to the more primitive conifers. The wood resembles that of the araucarian conifers, but, unlike the true conifers, the leaves are remarkably large. The trees grow to a large size, sometimes to over 100 feet in height and 10 feet in girth at the base. They appeared in Devonian time and were well represented in the Devonian rocks of eastern Canada; in the Carboniferous period, as stated above, they reached their maximum development and rapidly declined thereafter. *Cordaites* and *Dadoxylon* are common genera in the Carboniferous rocks of Nova Scotia and New Brunswick.

CARBONIFEROUS INVERTEBRATES

Carboniferous time witnessed many changes in the invertebrate life; the old Palæozoic types, so long dominant, began to give place to new orders of beings destined to reach a remarkable development in the following era. Furthermore, there are many distinctive features in the life of the time which enable us to summarise its main characteristics and to make a fairly clear comparison with the fauna of the Devonian.

The great groups of corals, trilobites, and nautiloids show a marked decline; the pelecypods, gastropods, and the new type of cephalopod increase; crinoids and blastoids reach their maximum development; protozoa spring suddenly to a position of great importance; and the higher arthropods, including many air-breathing forms, become a striking feature of the life of the time.

The Acadian Carboniferous strata were deposited in a sea which was quite distinct from the great mid-continental ocean; in consequence, the fossils differ somewhat from the more typical American forms. The strata of the Rocky Mountain area are very poor in fossils, and the few that occur are not well preserved. To the Canadian student, therefore,

Carboniferous invertebrates are of little practical value, although their importance in general historical geology is as great as ever.

The following list includes a few of the most characteristic Carboniferous fossils:

PROTOZOA. These little unicellular organisms are represented by a great number of forms which, in places, form whole layers of rock. *Fusulina,* a small spindle-shaped form, is the most common example.

CORALS. Of the Devonian genera many are extinct, but some survive, particularly *Diphyphyllum.* The most characteristic form, however, is *Lithostrotion,* a compound coral having a rod-like axis in the centre of each corallite.

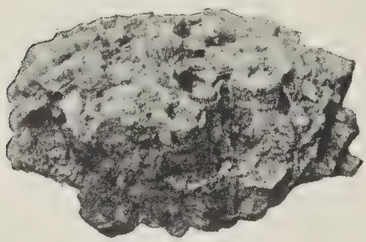

FIG. 133. THE TYPICAL CARBONIFEROUS CORAL

Lithostrotion canadense. One-fourth natural size.

Echinoderms. Crinoids and blastoids reach their maximum development. Of the former, the genera are remarkably numerous; *Platycrinus* and *Actinocrinus* will serve as examples. Blastoids are at the maximum development and disappear with the close of the period. *Pentremites* is the commonest genus. For the first time sea urchins are important; they differ from all modern forms in that the shell is composed of more or fewer than twenty rows of plates. *Melonites* and *Archæocidaris* are common examples.

BRACHIOPODS. These creatures, long dominant among the shell fish, are still numerous, but in this period they begin to yield to the molluscs which are destined to replace them in the seas of later ages. *Spirifer* is still abundant, but the loop-bearing types, *Terebratula* and *Dielasma,* are increasingly important. The most characteristic of all the brachiopods is *Productus.* In the Acadian Carboniferous *Productus semireticulatus,* a cosmopolitan species, is common; other examples are *Spirifer glabra* and *Dielasma sacculus.*

BRYOZOA. A peculiar screw-like bryozoan, *Archimedes,* is one of the most striking fossils of the period; it is entirely confined to rocks of this age.

PELECYPODS AND GASTROPODS. Both these groups are more strongly represented than before, but the majority of

the species belong to old types. More particularly in the case of the former group, there is a significant admixture of new forms heralding the great change to come. *Euomphalus* and

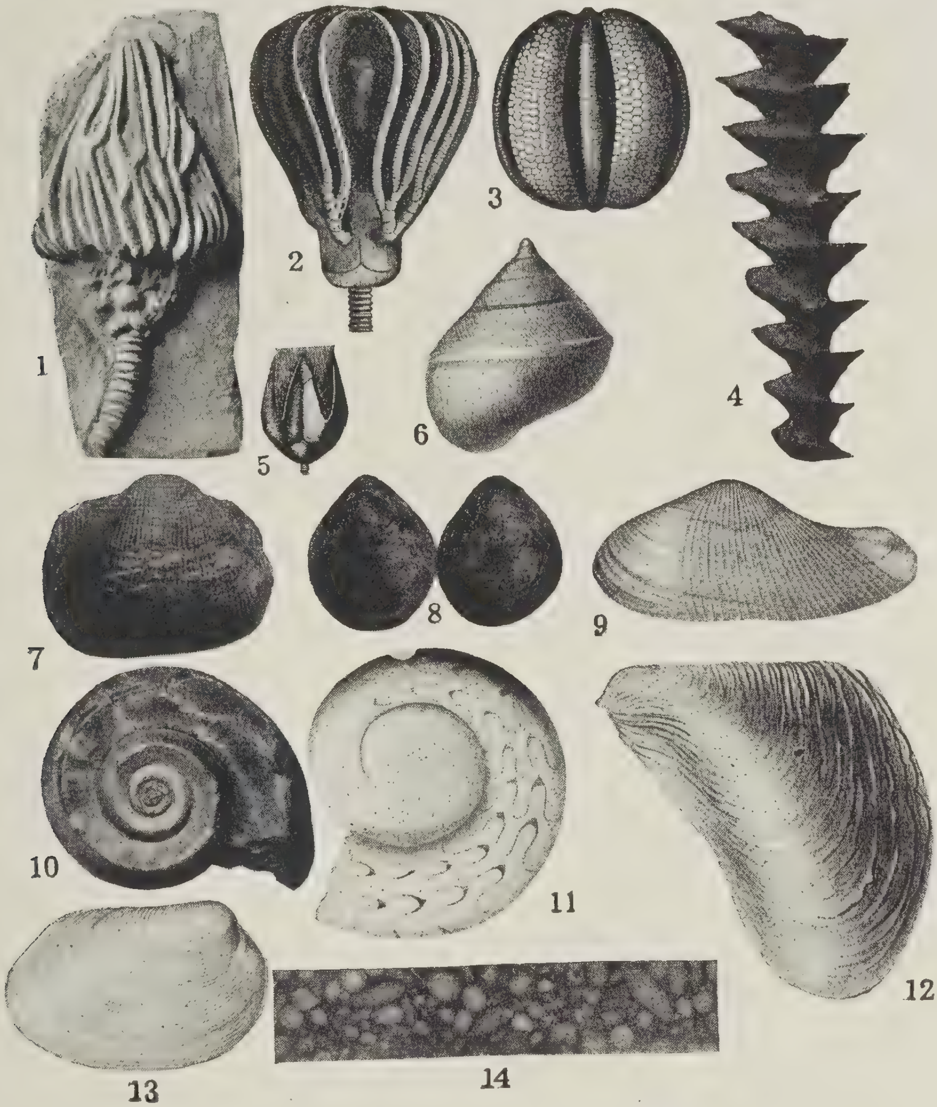

FIG. 134. CARBONIFEROUS MARINE INVERTEBRATES

1. *Actinocrinus multiramosus*, three-eighths natural size; 2. *Platycrinus tricondactylus*; 3. *Melonites multiporus*, three-eighths size; 4. *Archimedes wortheni*, three-fourths size; 5. *Pentremites sulcatus*, half size; 6. *Pleurotomaria mississippiensis*, half size; 7. *Productus semireticulatus*, seven-eighths size; 8. *Dielasma sacculus*, seven-eighths size; 9. *Allorisma pleuropistha*, half size; 10. *Euomphalus pentangulatus*; 11. *Goniatites lyoni*, three-eighths size; 12. *Myalina recurvirostris*, three-eighths size; 13. *Edmondia trapeziformis*, half size; 14. *Fusulina cylindrica*, in rock.

Bellerophon are the commonest gastropods, and *Schizodus* and *Myalina* are typical pelecypods.

CEPHALOPODS. A few *Orthoceras* survive, and there are many

coiled nautiloids. The nautiloid type of cephalopod continues to exist to the present, but it never again occupies a position of importance. The most characteristic cephalopods are the *goniatitoids,* with more strongly angulated sutures than in the clymenoids of the Devonian.

TRILOBITES. Only one family, the *Proëtidæ,* remains: it is represented by five genera, of which *Phillipsia* is the most abundant.

THE HIGHER ARTHROPODS. The higher invertebrate

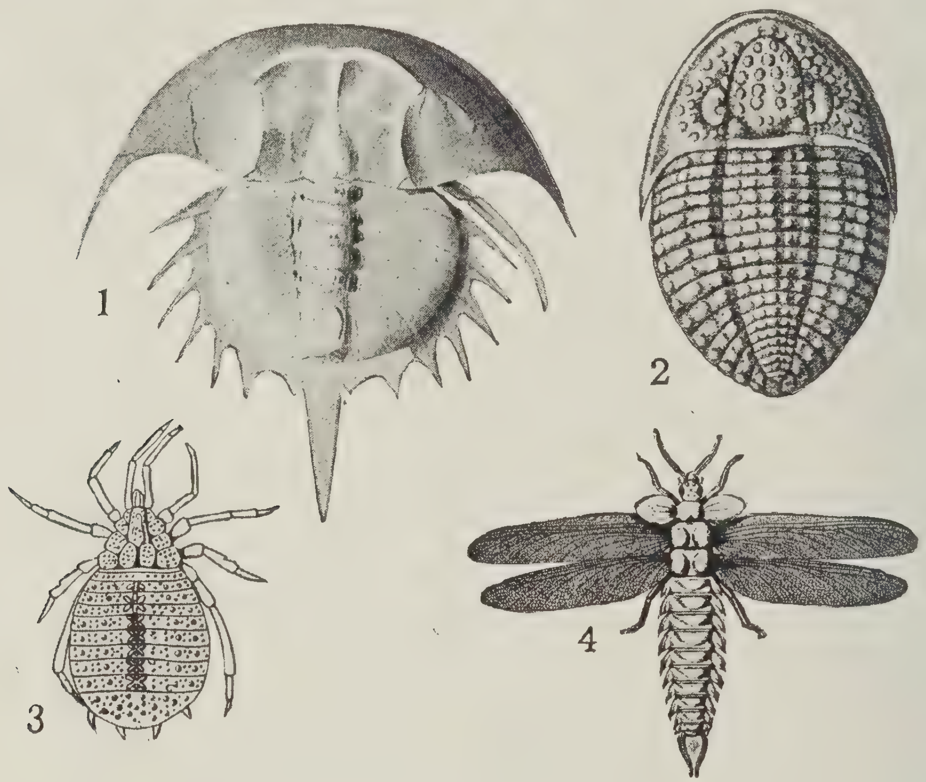

FIG. 135. CARBONIFEROUS ARTHROPODS

1. *Prestwichia danæ*; 2. *Phillipsia lodiensis*; 3. *Eophrynus prestwichii* (spider); 4. *Stenodictya* (insect). *After Handlirsch.*

animals with jointed limbs reach a development hitherto unknown. Among the aquatic forms the ostracods, phyllocarids, and phyllopods occur in abundance. Eurypterids survive, and *Prestwichia* is a very characteristic related form.

Spiders, scorpions, and myriopods occur in abundance, and there is a remarkable development of insects: these belong mostly to the types with straight or net-veined wings, and sometimes measure more than two feet from tip to tip of the

wings. *Haplophlebium barnesii*, a form with seven inches' expanse of wing, was found in the Carboniferous rocks of Cape Breton.

CARBONIFEROUS VERTEBRATES

FISH. The armoured fish of the Devonian disappear with its close, and the crossopterygian ganoids give place to another type, in which the extremity of the vertebral column turns up into the dorsal lobe of the tail and the paired fins are without the scaly axis and marginal fringe. A family of these fish, the *Palæoniscidæ*, reached a position of pre-eminence; it is represented by numerous species in the Carboniferous rocks of the world, and by at least five from the Lower Carboniferous

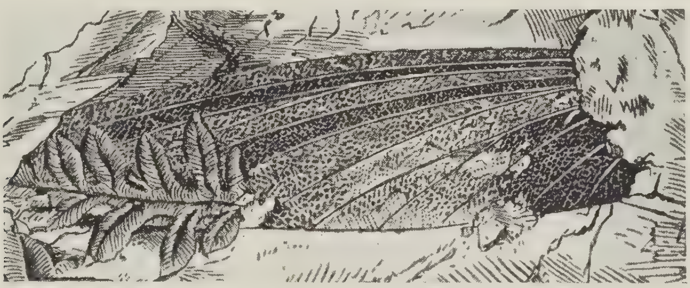

FIG. 136. WING OF HAPLOPHLEBIUM BARNESII
A Canadian Carboniferous insect. *From Dawson, "Acadian Geology."*

rocks of New Brunswick. *Rhadinichthys alberti*, a small fish from the Albert shales of New Brunswick, is the best known Canadian form.

In addition to the *Palæoniscidæ*, the Carboniferous fish fauna consists chiefly of a few survivals of crossopterygians and many lung-fishes and sharks.

AMPHIBIA. The lowest air-breathing vertebrates are known, on the evidence of footprints only, from the Devonian rocks. In Lower Carboniferous time these impressions are more numerous, and in the upper part of the system not only footprints, but actual skeletons have been found. These animals are all small, not exceeding three feet in length; they are mostly salamander-like, but legless, eel-like forms are known as well. Many years ago a number of imperfect skeletons of these primitive amphibians were found by Sir William Dawson at the South Joggins, Nova Scotia. Prior to

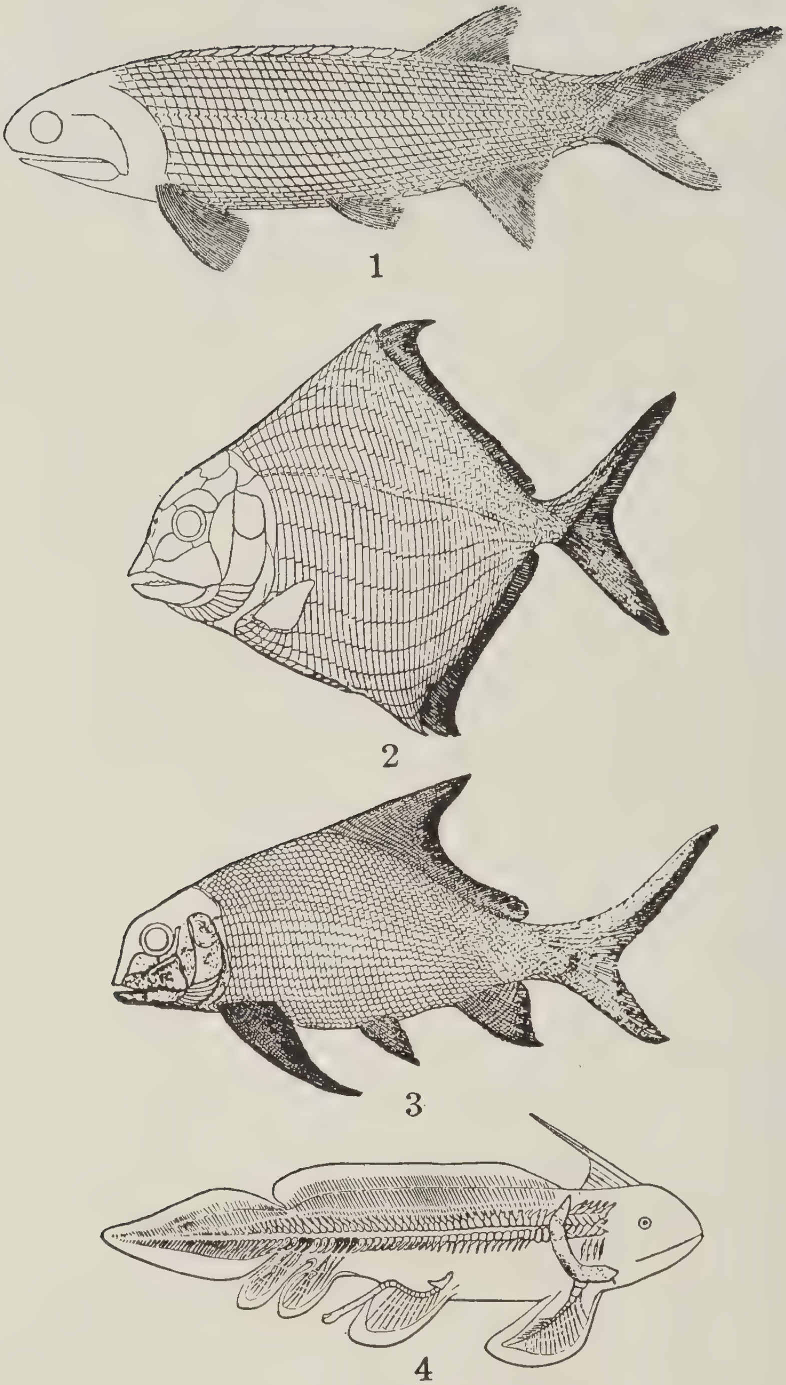

FIG. 137. CARBONIFEROUS FISH

1. *Rhadinichthys alberti*, Albert shales of New Brunswick; 2. *Cheirodus granulosus*, Scotland; 3. *Eurynotus crenatus*, Scotland; 4. *Pleuracanthus gaudryi*, France. No. 1 seven-eighths natural size, *after Lambe;* Nos. 2 and 3 reduced, *after Traquair;* No. 4 reduced, *after Brongniart.*

these discoveries, in 1841, Sir William Logan recorded the occurrence of footprints at Horton Bluff—the first evidence of Carboniferous air-breathing vertebrates found in the world. Exclusive of footprints, at least seventeen species of *Amphibia* were described by Dawson and the great English palæontologist, Owen, from the Carboniferous rocks of Nova Scotia. For the Canadian student no better examples of Carboniferous amphibians could be cited than those illustrated in

FIG. 138

1. Restoration of Carboniferous landscape in Nova Scotia, showing primitive amphibians; 2. Erect trunk of *Calamites* in which the bones of some of the amphibians were found. *From Dawson, "Acadian Geology."*

Figure 138, a reproduction of Dawson's original woodcut, published in 1878.

REPTILES. It has long been a matter of dispute whether or not true reptiles appeared in Carboniferous time. Professor Williston now holds the opinion that a single skeleton, lacking the skull, is the only known representative of Carboniferous reptiles. The remains were found at Linton, Ohio, in Upper Carboniferous rocks, and have been given the appropriate name *Eosauravus*.

Not much is known of conditions on the dry land during the Carboniferous, but in eastern Canada, as in many other parts of the northern hemisphere, there were vast marshy

forests in the lowlands with rank, almost tropical, growths. Air-breathing inhabitants were numerous, and the life was varied, for Sir William Dawson has shown that there were little snails feeding on the fern leaves, myriapods burrowing in decaying tree-trunks, many insects flitting among the trees, and scorpions and spiders on the look-out for them. Even the vertebrates, in the form of little amphibians, crept up the tree-trunks and rested in hollow stumps; so that the lowlands, at least, displayed a varied and interesting life.

Judging by the coal plants found even within the Arctic Circle in the great northern islands of Canada, the climate and the life seem to have been uniform all over the world.

CHAPTER X

THE PERMIAN PERIOD

This system receives its name from the province of Perm in Russia, where it is well developed. In Europe the rocks of the system rest conformably or unconformably on the underlying Carboniferous strata. In North America no structural break marks the upper limit of the Carboniferous; in consequence, the Permian system is ill defined: it fades imperceptibly into the Upper Carboniferous or Pennsylvanian, and in the opinion of American geologists is not worthy of being considered a great system.

PHYSICAL EVENTS OF THE PERMIAN IN NORTH AMERICA

The shallow seas of Upper Carboniferous time had begun to retreat before the close of that epoch, and by the middle of the Permian they had withdrawn almost entirely from the present area of the continent: in consequence, no marine strata were deposited over regions now accessible, and we have no record of sedimentation for Upper Permian time in North America. In other parts of the world, however, notably in South Africa, a continuous record is available which fills in the gaps that would exist in geological history were North America to be relied on to tell the whole story.

We have already seen that much volcanic activity was manifested in the Pacific Coast region during the Upper Carboniferous; this state of unrest continued into the Permian and may be regarded as the warning of great events to come, for one of the most profound disturbances that have affected the earth's crust occurred toward the close of Permian time. We have seen that the continent had been sufficiently uplifted to drain off the seas by the middle of the period. This upward movement continued through the closing stages of the

Permian, and was manifested with such intensity in eastern North America that the Appalachian mountains were elevated, the terrestrial strains relieved, and the continent prepared for another cycle of erosion. To this great event the name *Appalachian revolution* is given: with it the old order of things closes and the Palæozoic era ends.

THE PERMIAN IN OTHER CONTINENTS

Hitherto the geological history of the world can be fairly well illustrated by using North America as an example. The conditions in Permian time, however, were so varied in different parts of the globe that general deductions cannot be drawn from the history as revealed by the rocks of this continent.

In western Europe the Permian rocks are chiefly conglomerates, sandstones, and shales of a prevailing red colour. The red colour, the paucity of fossils, and the occurrence of beds of gypsum indicate deposition under desert conditions. The strata are usually unconformable with the underlying Carboniferous, and seem to have been rapidly deposited in isolated basins. Passing westward into European Russia and thence into Asia, Permian rocks are found over wide areas; they are truly marine deposits with a rich pelagic fauna.

In the southern hemisphere very different conditions seem to have prevailed. North of the equator, in India, there is a great accumulation of sediments of freshwater origin known as the *Gondwana system,* including strata varying in age from Carboniferous to Middle Mesozoic. The Permian system as recognised in Europe is not to be distinguished, but the lower part of the Gondwana is roughly correlated with it and is called *Permo-Carboniferous.*

In South Africa the great *Karoo formation,* covering thousands of square miles, is comparable in age, in fossils, and in conditions of sedimentation with the Gondwana of India. In Australia, resting on true Carboniferous rocks, is a series of strata also ascribed to the Permo-Carboniferous. These rocks are coal-bearing and show a flora comparable with that of India and South Africa; in this case, however, strata

of marine origin are associated with the fresh or brackish water deposits. In South America, also, the characteristic plants of the Gondwana system are found in strata ascribed to Permo-Carboniferous age.

On account of the striking similarity in the plant life of these regions, and for other reasons, many geologists believe that Asia, Africa, Australia, and South America were united into a great transverse continent, to which the name *Gondwana Land* has been given.

A most remarkable feature, common to all the regions mentioned above, is the occurrence of great beds of boulder clay, filled with striated stones and resting on a striated surface of the underlying formations. The lowest formation of the Karoo series of South Africa, the *Dwyka*, is of this nature; the *Talchir* conglomerate at the base of the Gondwana of India is similar; and the Permo-Carboniferous deposits of Australia and South America present the same interesting feature.

In view of these facts, geologists are now agreed that an extensive glaciation affected the southern hemisphere and even reached north of the equator in Permo-Carboniferous time—a glaciation exceeding that of more recent times in the northern hemisphere. To this great event the name *Permo-Carboniferous Ice Age* is given.

If the geological history of South Africa and Australia had been written before that of Europe and North America, the great divisional lines would have been drawn at different levels. Instead of the Australian geologists having to use such terms as Permo-Carboniferous, we should be struggling with hyphenated words derived from great systems established by our antipodean cousins.

THE PERMIAN SYSTEM IN CANADA

Permian strata are of comparatively small extent in Canada; two or possibly three areas may be recognised, as follows:

1. Acadian Area. Conformably overlying the Coal Measures is a series of reddish sandstones and shales, sometimes with thin seams of coal. The rocks occur in Nova

Scotia along the shores of Northumberland strait and form the whole of Prince Edward island. The prevailing red colour of the rocks and soils, together with the deep green of the vegetation, gives a very characteristic appearance to the scenery of the island. The better grades of sandstone are used for building, and the shales for brick-making. That these rocks are to be exactly correlated with the Permian of Europe is not established; they are not separated by any physical breaks from the Coal Measures and do not contain conclusive marine fossils. In consequence, the term Permo-Carboniferous is less liable to create a false impression.

2. Rocky Mountain Area. In the mountains of southern Alberta, the hard Rocky Mountain quartzite of the Carboniferous is covered by dark-coloured shale containing many hard bands. This formation is not exposed on the summits of the eastern ranges, as it has been removed by erosion. On the back slopes, however, it is found in the lengthwise valleys, as near the Banff Hotel on the line of the Canadian Pacific Railway. It is to be noted that some authorities consider these shales to be of Triassic rather than of Permian age.

3. Pacific Coast Area. It is generally thought that the mixed sedimentaries and volcanics of the coast region which we have ascribed to the Upper Carboniferous may contain also strata of Permian age.

LIFE OF THE PERMIAN

The life of Permian time, regarded in a broad way, shows a continuation of the Carboniferous types, both animal and vegetable, with an increasing admixture of the newer life which is to become dominant in the next era. The outstanding features are the unique Glossopteris flora of the Gondwana and the development of air-breathing vertebrates.

Plants. Of the numerous Carboniferous plants, many species survive into the Permian; other species, and even genera, become extinct with the close of the Carboniferous. Perhaps the most significant difference is the profusion of cycads, a type of life which became dominant in the later Mesozoic era.

The remarkable Glossopteris flora consists of numerous closely related ferns, which developed under the conditions of cold climate which prevailed in the southern hemisphere. The plants were hardy and remarkably cosmopolitan, for identical species have been found in India, Africa, and South America.

FIG. 139. THE GLOSSOPTERIS FLORA

Glossopteris browniana. After Zittel.

INVERTEBRATES. A very impoverished fauna is found in the Permian strata of western Europe, and the Permo-Carboniferous rocks of Canada are almost destitute of the remains of marine organisms. The Permian strata of Russia, however, yield an abundant fauna, on which must be founded any general remarks on the invertebrate life of the period. This life is strikingly like that of the Carboniferous, and shows the same tendencies in a more accentuated form. For instance, the eurypterids have disappeared, the trilobites have dwindled still further, and the ascendancy of the molluscs over the brachiopods, and of the goniatitoids over the nautiloids, is more marked. The crinoids, so abundant in the Carboniferous, show a remarkable decline, as their remains are rare in Permian rocks.

FIG. 140. PERMIAN AMPHIBIAN

Archegosaurus dechini. From Zittel after H. von Meyer.

FISH. The fish fauna of the Permian is very similar to that of the Carboniferous, with the *Palæoniscidæ* predominating: sharks and lung-fishes are also abundant. The genus *Palæoniscus* is confined to the Permian.

AMPHIBIANS. The Permian, together with the succeeding

Triassic period, is characterised beyond all else by the great development of amphibian life. The amphibians of to-day are small creatures like the common frog, and play but a subordinate part in the life of the time; in the Permian they were large creatures and exercised dominion over the animal life of the period.

These early amphibians differ from frog-like creatures in that the bones of the side of the head are continuous, and not opened up as in the frog; on this account they are called *Stegocephalia*, or "plated cheeks." Some of them, also, have the enamel of the teeth enrolled in a peculiar manner, which

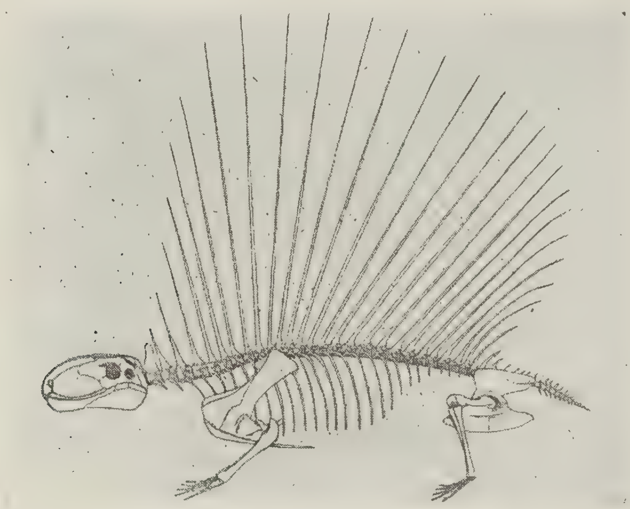

FIG. 141. PERMIAN REPTILE

Dimetrodon incisivus. About one-twenty-fifth natural size. *From Case, "Pelycosauria of North America."*

gives a very complicated appearance to a cross section; hence the name *Labyrinthodontia*, or "labyrinth-toothed."

Of the numerous Permian stegocephalians, *Branchiosaurus* and *Archegosaurus* may be cited as examples. The former is a small type covered above and below with an armature of small hard scales; the latter is a fairly large European type of labyrinthodont, and is represented in America by a similar form, *Eryops*.

Reptiles. The great ascendancy to be enjoyed by reptiles at a later date is foreshadowed in Permian time, for not only are they numerous, but give evidence of adaptation to various modes of life. Water, marsh, and land-dwelling forms are

known, and even types adapted to an arboreal existence. The Lower Permian beds of Texas have yielded many skeletons, and the Karoo formation of South Africa is famous for the number and variety of its reptilian remains. *Pareiasaurus* is a large, amphibian-like, massive, land-dwelling reptile from the Karoo; *Dimetrodon* and *Aræoscelis* are examples of the Permian reptiles of Texas. Aquatic types are represented by numerous small forms from South Africa and South America, *e.g. Mesosaurus.*

The Permian seems to have been a time of stress for the inhabitants of the world, great ice sheets and also great deserts taking the place of the mild monotony of the Carboniferous. This probably accounts for the great changes taking place in the vertebrates.

CHAPTER XI

SUMMARY OF THE PALÆOZOIC ERA

In previous chapters we have become acquainted with the great events of the long periods extending from the opening of the Cambrian to the close of the Permian, and which together constitute the Palæozoic era. The Cambrian opened with a continent of unknown extent on which successive layers of rock, some here, some there, were laid down in seas which invaded the land one after the other throughout the whole era. The successive floodings and retreats have been made use of to define the periods. In some cases the rocks of the different systems are separated by strong unconformities, in others there is scarcely a perceptible break between successive systems.

While terrestrial movements were going on gradually throughout the whole era, certain times were marked by upheavals of such magnitude as to deserve the name of revolutions. The more important of these, all of which were manifested much more strongly on the eastern side of the continent, were the Taconic disturbance at the close of the Ordovician period, the movements accompanied by volcanic activity at the close of the Devonian, and the great Appalachian revolution which brought the era to a close.

Wide-spread seas and consequent great formations were characteristic of the Ordovician; minor oscillations and more local formations characterised the latter part of the era.

Physical events during the Palæozoic were not essentially different from those of earlier and of later time, and there is nothing in their nature particularly characteristic of the era: it is to the life history that we must look for a means of defining the Palæozoic.

The era, as the name implies, is essentially the time of "ancient life," a time in which all the creatures were very different from those now inhabiting the globe. Nearly all

the great classes of organisms, with the exception of the flowering plants, birds, and mammals, had at least some representation. Among the plants, the sea weeds and vascular cryptogams were predominant; invertebrate groups entirely confined to the era are graptolites, stromatoporoids, cystids, blastoids, trilobites, and eurypterids; other invertebrate groups, prominent but not exclusively Palæozoic, are bryozoans, brachiopods, and nautiloids. Vertebrates are represented by archaic fish, and towards the close of the era by amphibians and reptiles.

CHAPTER XII

THE MESOZOIC ERA—THE TRIASSIC PERIOD

In previous chapters we have followed the great events of the long Palæozoic periods; we have seen how the ever-restless seas have flooded and ebbed, always leaving a rock-written record, the pages of which have been pieced together to make the history of Palæozoic time. We have seen that this history is continuous, although we have failed to find all the pages, and we have made use of physical disturbances and faunal changes as punctuation marks for our story, or in other words, to divide the era into periods and epochs. In entering upon the consideration of another great era it is well to keep in mind this continuity of geological history. Let us carefully avoid the conception of the Mesozoic as a new age marked off from the Palæozoic by some tremendous catastrophe. Let us regard it, rather, as a continuation of the story, a new chapter written under different conditions, but fading insensibly into the previous one. It is true that an unrecorded interval makes the division a very real one in some parts of the world, but it is equally true that there is absolutely no observable break between the two groups of rocks in others.

Our study of the Palæozoic periods has shown us that the rise and fall of races of organisms furnishes evidence of the utmost importance towards the orderly arrangement of our story into convenient chapters. The races of the Palæozoic appeared, reached a maximum, and in some cases declined and fell, but the process was gradual and extended over millions of years. The same conception of gradual change must be applied to the life of the Mesozoic as compared with that of the Palæozoic. In a broad way there is a great difference between the faunas and floras of the two eras, but nearly all the great races characteristic of Mesozoic time had their inception in the latter part of the Palæozoic; on the other hand, some races essentially Palæozoic lingered on into Mesozoic time. Reptiles, amphibians, ammonites, and cycads,

the dominant races of Mesozoic time, had all appeared before the close of the Permian, and the occurrence of *Orthoceras* in Triassic rocks attests the survival of a purely Palæozoic type into the lower part of the Mesozoic.

The Mesozoic, or era of "middle life," is divided by European geologists into three periods: *Triassic, Jurassic,* and *Cretaceous.* American geologists are now inclined to recognise four periods: *Triassic, Jurassic, Comanchian,* and *Cretaceous.* A general account of the physical, faunal, and floral characteristics of the era as a whole can be better understood after the periods have been considered: such a description is deferred, therefore, to Chapter XV.

THE TRIASSIC PERIOD

In Germany, where the rocks of this system were first studied, the strata may be distinctly arranged in three series: on this account the system was named *Triassic.* Names based on local peculiarities are generally found to be unsatisfactory, and the present instance is no exception, as a three-fold division of the rocks of the system is not observed in other parts of the world. The rocks of the type locality are largely of continental origin, and it has become customary to distinguish this facies as the *German Triassic.* On the other hand, the Triassic strata of the Alps are distinctly of saltwater origin; in consequence, the marine facies of the system is called the *Alpine Triassic.*

PHYSICAL EVENTS OF THE TRIASSIC IN NORTH AMERICA

The elevation which resulted from the Appalachian revolution left the eastern shore of the continent farther out to sea than at present; in consequence, any marine strata that were formed off the coast are still hidden beneath the waters of the ocean. Faulting and other terrestrial disturbances affected the eastern border region, with the production of gradually rising sections separated by narrow troughs or valleys. In these valleys were deposited coarse and rapidly accumulated

sediments derived from the decay of the neighbouring land-masses. The Triassic rocks of eastern North America, therefore, are distinctly of non-marine or continental origin. The state of unrest indicated by the extensive faulting of the time naturally facilitated igneous activity, with the result that many sills and flows of dark, basic rocks are associated with the sedimentaries. The close of Triassic time was marked in this area by a considerable elevation which affected the region to the east of the Appalachian mountains.

On the western side of the continent the waters of the Pacific ocean advanced over a wide area, and at the same time there was a tremendous manifestation of volcanic activity. All along the continental shelf, from California to Alaska, the Triassic sedimentaries are mingled with effusive and fragmental rocks of volcanic origin. A pronounced elevation accompanied by much folding of the rocks brought the Triassic period to an end in the Cordilleran region. This event was more profound in Alaska, but its effects were felt far to the south: it has been called the *Chitistone disturbance* by Schuchert.

THE TRIASSIC SYSTEM IN CANADA

Only in the extreme east and west of the Dominion are Triassic rocks known: they may conveniently be described under two areas:

1. Nova Scotia Area. The sedimentary rocks of this age are chiefly soft, friable sandstones, often associated with beds of gypsum. They occur on the shores of Minas basin and eastward to beyond Truro, also on Annapolis bay, and near Quaco on the New Brunswick side of the Bay of Fundy. These rocks rest with profound unconformity on the underlying strata, and were deposited in one of the narrow troughs which we have already seen to be characteristic of the physical geography of eastern North America in Triassic time.

Of greater importance than the sedimentaries are the flows of igneous rock, which in their more solid phases are dark-coloured diabases. Associated with these massive rocks are less compact, amygdaloidal flows of grey, green, red, or purple

colour. The whole south-east coast of the Bay of Fundy, from the extremity of the neck of Digby to Cape Split, is bordered by rocks of this kind; they also occur on the north shore of Minas basin and on Grand Manan island.

Many of the more massive flows show to perfection the columnar jointing so characteristic of volcanic rocks. This feature adds to the beauty and interest of a strip of bold and

FIG. 142. TRIASSIC TRAPS OF NOVA SCOTIA, CAPE BLOMIDON
From a photograph by Professor Clarkson, Wolfville, N.S.

picturesque coast which is in pleasing contrast to the prevailing mud flats of much of the Fundy shore.

The amygdules or almond-shaped cavities in the less massive flows in many cases have been filled with secondary minerals, particularly varieties of silica and zeolites. The disintegration of the rock sets free the harder substances which are often found in the form of pebbles at the base of the cliffs. Agate, moss agate, chalcedony, and amethyst, frequently of great beauty and decorative value, are to be obtained at many points along the coast.

2. British Columbia Area. Before describing the Triassic

rocks of this region it is advisable to review briefly the events which we have already considered. We have seen that a Pre-cambrian landmass existed in central and western British Columbia, that the Rocky Mountain geosyncline developed to the east of this old land, and that through all Palæozoic time strata accumulated in this depression to an enormous thickness. We have also seen that in the Upper Carboniferous epoch the region to the west of the Selkirk and Columbian mountains was depressed beneath the sea for the first time and became a new region of sedimentation, to which the name *Western geosyncline* is given.

In the Rocky Mountain geosyncline sedimentation continued into Permian time, but the disturbances at the end of the Palæozoic caused a temporary retreat of the sea, with the result that no strata were made in Triassic time in southern British Columbia. Authorities are not agreed on this point, as some ascribe the Upper Banff shale to the Triassic. Farther north, however, on the Peace river, undoubted marine Triassic rocks occur.

Over a wide region of the Western geosyncline sedimentary and volcanic rocks were deposited on the old Pre-cambrian floor in the Upper Carboniferous. It is possible that this condition continued into the Permian, but rocks of this age are doubtful and we may conclude that the Permian was largely a time of uplift and erosion in the western geosyncline. Triassic time, however, witnessed a second wide-spread depression in the region of the Western geosyncline and a deposition of sediments on the eroded surface of the Upper Carboniferous rocks. The Triassic sedimentaries, however, are insignificant in amount when compared with the great volume of igneous matter extruded during the period. From fissures in the earth's crust, and less frequently from volcanic craters, enormous masses of basalt and diabase were mingled with the sedimentaries. To the whole complex of igneous and sedimentary rocks the name *Nicola series* has been given; in places this series is 13,500 feet thick and consists, to nine-tenths of its volume, of igneous rocks.

A subsequent event, the formation of the Coast Range, has divided the region of the Western geosyncline into two great north-and-south belts. Both Carboniferous and Triassic rocks,

therefore, are to be found in two general regions of the old Western geosyncline—the central interior and the islands of the Pacific coast.

Although the copper, gold, and silver ores of southern British Columbia were formed at a later time, they frequently occur in association with the igneous rocks of Carboniferous and Triassic age. The Triassic limestones of the southern end of Texada island in the Strait of Georgia yield a very handsome red variegated marble.

LIFE OF THE TRIASSIC

Plants. The ascendancy of vascular cryptogams ends with the Palæozoic, for the life of the Triassic period shows a great increase in the gymnosperms as represented by conifers and more particularly by cycads. As these trees were destined to become dominant in the later periods of the Mesozoic, we have in the Triassic a time of change, an interregnum between the reigns of the cryptogams and the gymnosperms, with the new type already ascendant.

The great lepidodendrons and sigillarias had practically disappeared, but the calamites were represented by quite numerous species still of large size, but more closely related to the modern horsetails than *Calamites* itself. Ferns of new genera were also fairly abundant. Cycads with great green leaves (*Pterophyllum*) and the small-leaved, araucarian-like conifers (*Voltzia*) ruled the vegetation, at least of the higher lands, and imparted to the forest landscape of the time a somewhat gloomy and monotonous appearance.

The known species of Triassic plants are very numerous, and more than a third of these are American. The Triassic strata of Virginia have yielded the most abundant remains.

Invertebrates. The continental character of many of the Triassic sediments and the mingling of others with volcanic rocks have not favoured the preservation of marine fossils. Although the fauna, on the whole, is rather scanty on this account, nevertheless in regions of marine sedimentation, where the Alpine type of Triassic rock was formed, fossils of marine invertebrates are not wanting. The Palæozoic type of

coral has disappeared and its place is taken by a new race, the *Hexacoralla*, which has persisted to the present day. The decline of the brachiopods is pronounced, and their position is now subservient to that of the molluscs. The newer type of pelecypod which began to make its presence felt in Permian time is now firmly established and is represented by such genera as *Pecten* and *Myophoria*. Gastropods, while a little behind the pelecypods in development, are represented by new forms with which are mingled survivals of Palæozoic types.

Among the molluscs, the cephalopods show the most striking changes. The old nautiloid type is almost extinct, and the

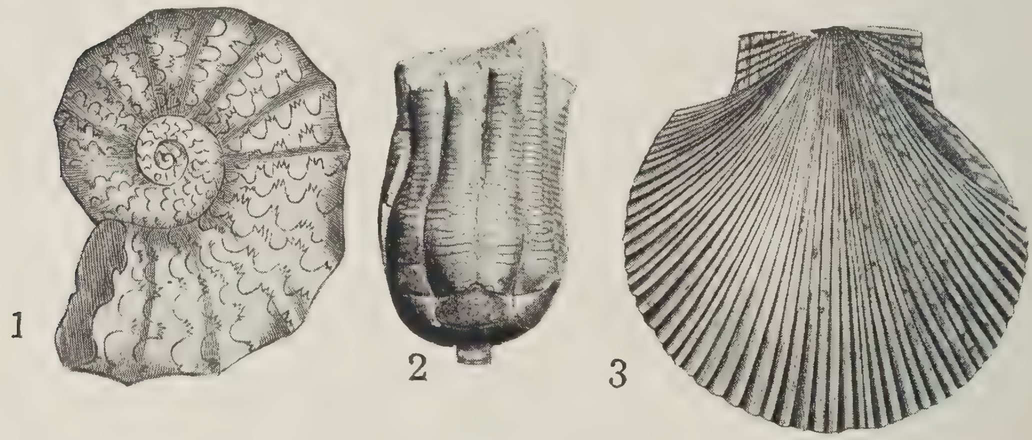

FIG. 143. TRIASSIC INVERTEBRATES

1. *Ceratites nodosus*; 2. *Encrinus liliiformis*; 3. *Pecten valoniensis*. 1, natural size; 2, one-half size; 3, two-thirds size.

goniatitoids give place to *ceratitoids* and *ammonitoids*. We have seen that the clymenoids of the Devonian and the goniatitoids of the Carboniferous are distinguished by an increasing angularity of the suture or line of union between the partitions and the shell wall. The ceratitoids have folded sutures with the backward turn of the fold crumpled; the ammonitoids show a remarkable degree of complexity in the folding of the suture. The amount of evolution accomplished by these organisms in the Triassic was remarkable. *Ceratites* is typically Triassic, and *Arcestes* is a good example of the type with highly developed sutures.

The echinoderms of the Palæozoic have all passed away. No cystids or blastoids are known in the Triassic, and the abundant

crinoids of the Carboniferous, decadent in the Permian, are now represented by an incoming race of different type. In the new type of crinoid the space inside the arms is not plated but is protected by a tough membrane, and the arms are more developed than in the Palæozoic forms. *Encrinus liliiformis* is a very typical fossil of the time. The modern kind of sea urchin with twenty rows of plates replaces the archaic type of the Palæozoic. *Cidaris* is the most abundant Triassic sea urchin.

The higher crustaceans are represented by the decapod *Pemphix.*

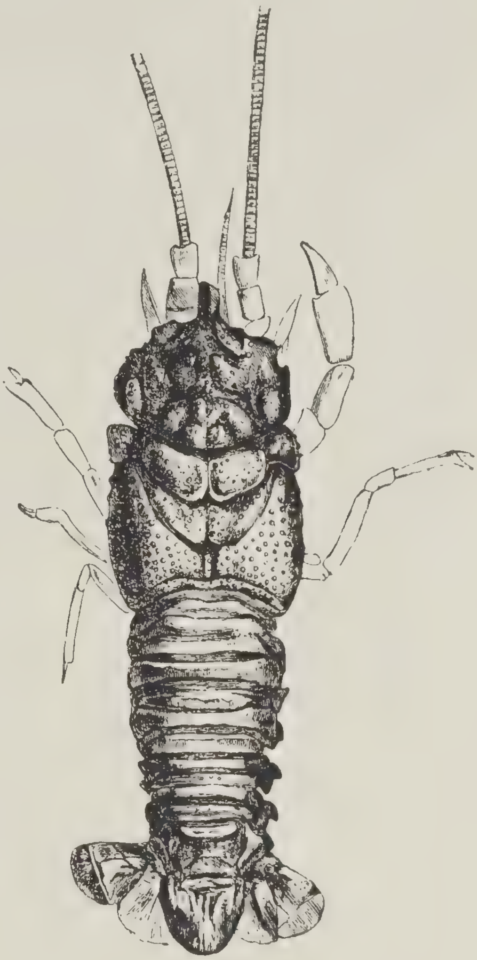

FIG. 144. TRIASSIC CRUSTACEAN
Pemphix sueurii. After Zittel.

FISH. The Triassic fish fauna is not remarkable and bears a strong resemblance to that of the Permian. Heterocercal ganoids and other ganoids of a higher type were dominant. Sharks are known by teeth and spines, and the last of the marine lung-fishes by numerous teeth of *Ceratodus*.

AMPHIBIA. These creatures attained their maximum development in this period, which together with the Permian may be called the *Age of Amphibia*. The labyrinthodont type of stegocephalian is particularly abundant, and is represented by some forms of great size, *e.g. Mastodonsaurus,* with a head a metre and a quarter in length.

REPTILES. We have seen that a remarkable development of reptilian life was a feature of the Permian; in the Triassic this development continued to such a degree that the forerunners of all the great tribes of reptiles, except the snakes, had appeared before the close of the period. The small reptiles of the Permian seem to have had but a short term of existence, for all the species, and in many cases the sub-orders to which

they belong, had become extinct before the opening of Triassic time.

A remarkable group of reptiles from the Karoo formation of

FIG. 145. TRIASSIC WATER REPTILE

Nothosaurus. From Williston, "Water Reptiles, Past and Present."

South Africa is the *Theriodontia,* or beast-toothed forms. These animals show many anatomical peculiarities which suggest a

FIG. 146. PRIMITIVE TRIASSIC CROCODILE

Mystriosuchus. From Williston, "Water Reptiles, Past and Present."

mammalian relationship, and it is confidently believed by many authorities that it was from these reptiles that the

great race of mammals arose. *Cynognathus* is one of the most typical examples.

The extraordinary sea-going reptiles which became so abundant in the later periods of the Mesozoic, and which are more fully described on page 300, had their beginning here. The long-necked type is represented by *Nothosaurus* and primitive examples of *Plesiosaurus*, and the short-necked type by primitive ichthyosaurs.

True crocodiles had not yet appeared, but an archaic order known as the *Parasuchia* is particularly characteristic of the Triassic. These creatures are crocodile-like, but differ in the constant possession of a long snout and in the position of the external nostrils, which are placed far back near the eye, instead of being situated at the end of the snout. *Belodon, Mystriosuchus,* and *Rutiodon* are typical examples.

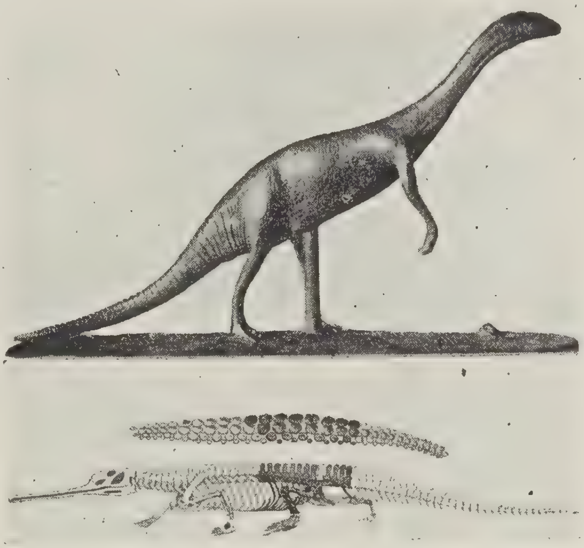

FIG. 147. TRIASSIC VERTEBRATES

Upper figure, *Anchisaurus colurus*, one of the earliest dinosaurs. Lower figure, *Rutiodon manhattanensis*, a phytosaur or ancestral crocodile. *After Lull and Matthew.*

The most extraordinary group of all the reptiles is that of the *dinosaurs,* which will be more fully considered later. It is interesting to note that the earliest examples of this great race of land or marsh-dwelling reptiles are known from the Triassic rocks. *Anchisaurus* is a form from Connecticut well worthy of note. From Prince Edward island a related dinosaur has been described under the name *Bathygnathus borealis.*

In addition to actual skeletons, the Triassic rocks have yielded a remarkable number of footprints which were the occasion of much speculation before the discovery of distinct remains.

CHAPTER XIII

THE JURASSIC PERIOD

While the term Triassic is of German origin, the Jurassic period owes its name to Swiss and French geologists, by whom the rocks of the system were studied in the Jura mountains. If priority of name were strictly adhered to we should call this system the *Oölite,* a name given to it at an earlier date by the great English geologist, William Smith. As the term Oölite refers to a structural peculiarity of some of the rocks, it has been abandoned in favour of the name of geographical origin.

The Jurassic is a great system which has been recognised in many parts of the world, but the conditions of sedimentation were very different at different places, and distinct changes are to be observed within limited geographical bounds. The Jurassic formations are local in development, a condition which seems to increase with the passage of geological time.

PHYSICAL EVENTS OF THE JURASSIC IN NORTH AMERICA

Throughout Jurassic time a very large part of the present area of North America remained out of water and consequently was subject to profound erosion. Jurassic history is written in North America only in the Pacific border region. Early Jurassic time was marked by a marine invasion which affected the coast and islands in the northern part of this district and farther south advanced over parts of California, Oregon, and Nevada. In later Jurassic time a greater flood from the north (Logan sea) advanced over a large part of Alaska and British Columbia, extending as far south as the state of Utah.

We have seen that a state of unrest existed in this area during the Permian and Triassic, and that volcanic activity was manifested on a large scale. Again, in the Jurassic vul-

canism was pronounced with a great outpouring of basic lavas and other volcanic products along the continental shelf. The period was brought to a close by a profound elevation whereby the Cascade and other ranges of mountains were formed. This event was accompanied by the most extraordinary outburst of molten matter that has occurred since the Pre-cambrian.

From Lower California to Alaska the pre-existing rocks were torn open, invaded, and lifted up as remnants by enormous upwellings of igneous magmas of an acid nature, which on consolidation have resulted in rocks of a general granitic aspect. These rocks in the form of multiple batholiths now constitute whole ranges of mountains, *e.g.* a great range in the Sierra Nevada mountains and the Coast Range of British Columbia.

THE JURASSIC SYSTEM IN CANADA

It is evident from what has already been said that Jurassic strata can appear only in the western part of Canada. Owing to the inaccessible location of much of the northern region, in which Jurassic rocks are thought to occur, the limits of the system have not yet been worked out in detail. The known occurrences may be roughly divided into four areas as below:

1. Rocky Mountain Area. We have seen that the Rocky Mountain geosyncline continued to be an area of deposition until the close of Permian time, that the sea was partially withdrawn during the Triassic, and that it returned in the latter half of the Jurassic period. The upward and downward movements whereby these changes were effected must have been of a broad and gentle character, for the Jurassic strata rest with scarcely a disconformity on the Upper Banff shales of the Permian.[1] These rocks consist entirely of shales and constitute a formation known as the *Fernie*, which reaches in places a thickness of 1500 feet. The strata are fossiliferous and contain an abundance of ammonites and belemnites in

[1] The apparent conformity of the Upper Banff shales with the overlying Fernie beds has been used as an argument in favour of the Triassic age of the former. See pages 280 and 282.

places. Exposures are best seen in the valleys between the more easterly ranges. The rocks doubtless originally extended across the whole area occupied by these ranges, but since the uplift of the mountains they have been removed by erosion from the summits of the ranges. The eastward extension of the Fernie shale is proved by its occurrence, but with greatly diminished thickness, in the foothills east of the main mountains.

2. Interior British Columbia Area. The broad region lying between the Columbian mountains and the Coast Range constitutes the interior plateau area of British Columbia. In the southern part of this belt sedimentary strata of Jurassic age are doubtful; but farther north, along the line of the Grand Trunk Pacific Railway, the *Hazelton formation* contains fossils which attest its Jurassic age. The rocks are chiefly tufaceous sandstones and dark-coloured shales, which indicate that continental accumulations were mingled with marine deposits in building up the beds.

3. Yukon Area. Near the Alaska boundary and at other points in the far north sedimentary strata are found which are probably to be ascribed to the Jurassic system.

4. Coast and Islands Area. Jurassic rocks, chiefly argillites and limestones, occur on Vancouver island, Texada island, Queen Charlotte island, and other islands of the Pacific coast. In all cases they are much cut by volcanics and frequently interbedded with fragmental and extrusive rocks of igneous origin. The whole complex reaches a thickness of several thousand feet, and is referred to as the *Vancouver group*.

The association of the limestones with volcanic rocks has rendered them crystalline in structure: they are quarried for lime and cement-making, for use in the pulp mills, and for flux in metallurgical operations.

THE JURASSIC IGNEOUS ROCKS OF BRITISH COLUMBIA

During this period igneous activity was not shown in the region of the Rocky Mountain geosyncline; in consequence, the Fernie shale of this section is not associated with volcanic rocks. On the other hand, all the Jurassic rocks of the islands

are cut by dikes, covered by flows, and intermingled with fragmentaries. The most abundant volcanic rocks are andesites and andesite porphyries, but the more basic rocks, such as basalt, are not infrequent.

Of greater importance are the immense masses of granodiorite and related rocks, which in the form of batholiths appeared at the close of Jurassic time. For more than a

FIG. 148. SKETCH MAP OF BRITISH COLUMBIA

Showing the Coast Range batholith, the Nelson batholith, and other smaller masses of granite or related rocks. The Coast Range is not indicated on the Alaskan side of the boundary.

thousand miles along the coast, with a width varying from 30 to 120 miles, stretches the great Coast Range of mountains, which is made up entirely of these rocks. The appearance of this range marks a great change in the topography of British Columbia, for the region of the Western geosyncline is now cut into two.

Other less extensive but very large batholiths of granodiorite, some of which may be of slightly later age, occur at several places in British Columbia: most important of these

are the batholiths of Vancouver island and of Nelson, in the southern part of the province.

The rocks of the Coast Range and of the Nelson batholith are extensively quarried for building purposes. The stone is a grey to pink granodiorite, and it has been used for some of the finest structures in Victoria, Vancouver, and other western cities.

LIFE OF THE JURASSIC

In favoured localities the life of Jurassic time was exceedingly abundant and varied. The new type of life which was foreshadowed in the Permian and became ascendant in the Triassic now reaches a remarkable development. The varied conditions of sedimentation, marine, brackish, and freshwater, has permitted the preservation of a correspondingly varied fauna and flora, and the favourable character of many of the sediments has made possible the entombing of organisms of the most delicate structure.

The outstanding features of Jurassic life are:

(1) The dominance of cycads and conifers.

(2) The profusion of gastropods and pelecypods.

(3) The extraordinary development of ammonites and belemnites.

(4) The ascendancy among the fish of the "shining-scaled ganoids."

(5) The number and variety of reptiles.

The great development of Jurassic strata in Europe, the excellent preservation of the fossils, and the accessibility of the exposures have all contributed to the knowledge of these remains, of which about 15,000 species are known. In North America, as we have already seen, nearly all these favourable conditions were absent. Most of the continent was out of water all through Jurassic time, and the areas in which sedimentation did take place were subject to both contemporaneous and subsequent vulcanism. As a result of these conditions the Jurassic strata of North America have yielded a flora and fauna insignificant when compared with those of Europe.

In Canada the Fernie shale is fossiliferous in places, and

some of the layers of the Vancouver group in Queen Charlotte island have yielded many fossils. In both cases, however, the fossils are badly preserved and are frequently pressed flat. Of the great reptiles the Canadian Jurassic rocks have yielded no recognisable examples, although a few disconnected bones have been found. In the description of Jurassic life it is

FIG. 149. MESOZOIC PLANTS

Figures 1 to 6, cycads; Figures 7 and 8, conifers. 1. Stem of *Cycadoidea superba*, South Dakota; 2. Leaves of *Zamites feneonis*, France; 3. Leaves of *Otozamites beani*, England; 4. Leaf of *Nilssonia polymorpha* (Triassic); 5. Leaf of *Zamites arcticus*, Greenland; 6. Cone of *Williamsonia gigas* (Liassic); 7. *Voltzia heterophylla*; 8. *Araucaria microphylla* (Jurassic). Various reductions. *After Wieland, Saporta, Nathorst, Heer, and Schimper.*

apparent that we must look beyond Canada for typical examples.

JURASSIC PLANTS

Jurassic time is essentially the age of the gymnosperms; it shows an accentuation of the conditions of the Triassic period, *i.e.* the ascendancy of the gymnosperms over the cryptogams is more pronounced. Cycads occupy the first position and are represented by a great many genera, of which *Nilssonia*,

Otozamites, and *Williamsonia* will serve as examples. The second place is taken by the conifers like *Araucarites* and *Pinus*, and there is still a considerable survival of horsetails and ferns. The peculiar maidenhair tree (*Ginkoales*), which possibly appeared as low as the Carboniferous, is represented by a considerable number of species.

FIG. 150. MODERN CYCADS

Two Australian species. *After Mull, from Wieland, "American Fossil Cycads."*

JURASSIC INVERTEBRATES

The small unicellular animals (Protozoa) which first became important in the Carboniferous and afterwards somewhat declined are present in great numbers in the Jurassic rocks.

Hitherto the importance of sponges has been slight, as only in certain formations of the Silurian and Devonian has it been found necessary to refer to them. In the Jurassic, however, sponges are so abundant that they must be mentioned in the most elementary account of the life.

The skeleton of a sponge is composed of spicules of lime, silica, or horny matter. Most of the Jurassic sponges were of the siliceous type, and of these two kinds are known—one in which the spicules are heavy and strongly interlocked, lithistid or stony sponges (*Cnemidiastrum*), and another kind in which the spicules are delicate six-rayed structures so arranged as to build up a lattice-like skeleton of extraordinary delicacy (*Craticularia*).

CORALS abounded in favourable localities; they are even more numerous than in the Triassic and belong to the same type, the *Hexacoralla*, which is building up the coral reefs of to-day.

ECHINODERMS are represented chiefly by sea lilies and sea urchins. The former are of the soft-crowned, more modern type, which has been briefly described in the account of

Triassic life. In certain layers of Jurassic rocks crinoids are found in a wonderful profusion, which is excelled only by the maximum occurrences of the Carboniferous. The pear encrinite, *Apiocrinus rotundus*, and different species of the genus *Extracrinus* are particularly characteristic. The latter genus is very typical of Post-palæozoic crinoids, as it possesses a very long stem, a small cup with soft crown, and an extraordinary profusion of branching arms.

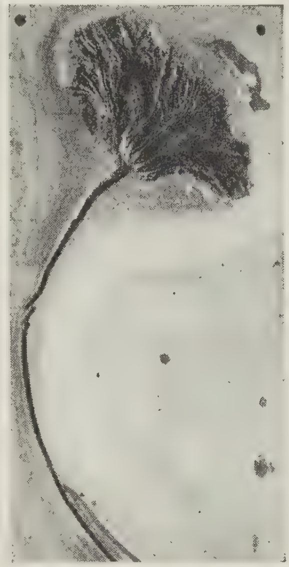

FIG. 151. LIASSIC CRINOID *Extracrinus sp.* From a specimen in the Royal Ontario Museum, Toronto. About one - twelfth natural size.

ECHINIDS, or sea urchins, are all of the modern type, *i.e.* they have twenty rows of plates: in this respect they agree with the Triassic forms. The prevailing Triassic sea urchin, with sub-spherical body and with the mouth and anal orifice situated at the two poles of the shell, begins to give place to the *irregular* echinid, in which the shell becomes depressed, heart-shaped, etc., and one or both of the openings are removed to a position near the margin of the shell. *Clypeus* and *Collyrites* are typical Jurassic genera.

PELECYPODS abound. The archaic types of the Palæozoic seas have passed away and their place is taken by the new life which first made its appearance in the Carboniferous. The great advance shown in the Triassic is maintained; numerous new families appear; and genera which persist to the present day are inaugurated. *Trigonia* is, perhaps, the most characteristic of Jurassic pelecypods: *Gryphæa*, *Lima*, and *Pecten* are also very abundant. Among the genera found in the Canadian Jurassic rocks are *Gryphæa*, *Pecten*, *Avicula*, *Cardium*, and *Ostrea*.

GASTROPODS are numerous, but they are scarcely as important as the pelecypods. The class is not so progressive, as some of the old Palæozoic genera still survive. The newer type is predominant, however, and is represented by many forms in which the mouth of the shell is no longer simple and

FIG. 152. JURASSIC PELECYPODS

1. *Lima gigantea*, two-fifths natural size; 2. *Gryphæa arcuata*, two-fifths natural size.

FIG. 153. SLAB FROM THE JURASSIC OF ENGLAND

Showing many specimens of the pelecypod, *Trigonia clavellata*. One-third size.

rounded as in most Palæozoic gastropods, but is drawn out into tube-like extensions. This change in the shell indicates that the animals had acquired a more specialised way of taking water into the gill cavity. *Nerinea* and *Purpurina* are common forms.

Cephalopods are the most characteristic invertebrate

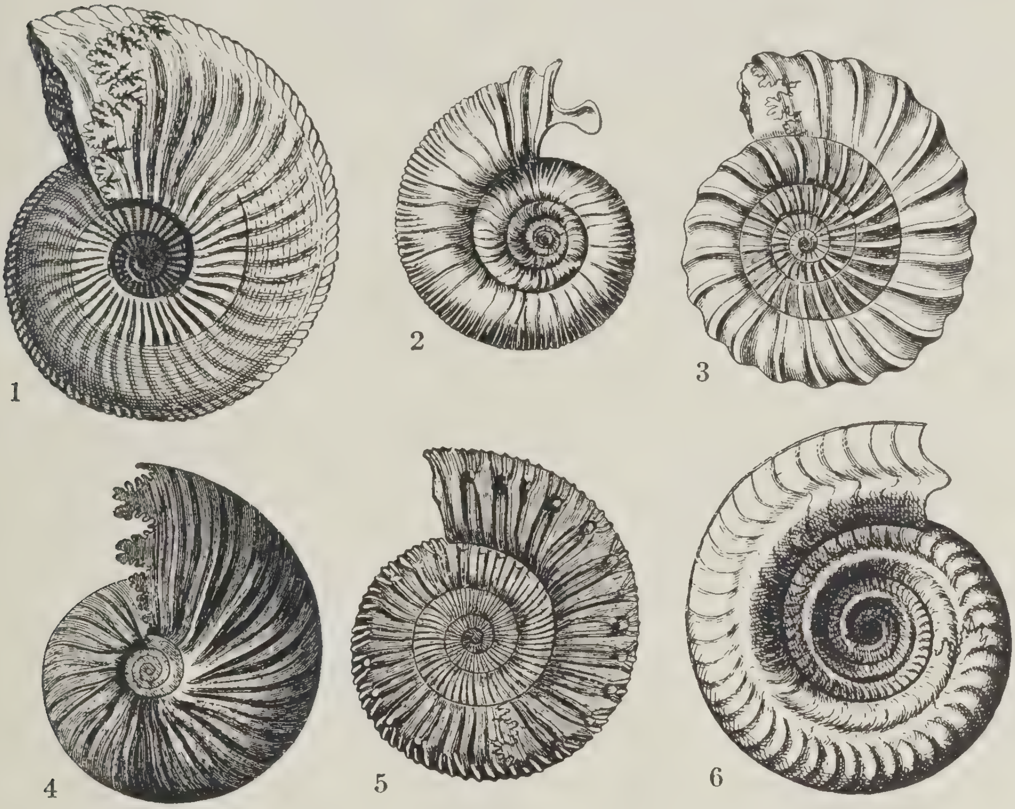

FIG. 154. LIASSIC AND JURASSIC AMMONITES

1. *Amaltheus margaritatus* ; 2. *Perisphinctes polyplocus* ; 3. *Ægoceras capricornis* ; 4. *Oxynoticeras oxynotus* ; 5. *Cœloceras subarmatus* ; 6. *Harpoceras bifrons. Figures reduced from Zittel.*

creatures of Jurassic time: they are represented by two groups, the *ammonites* and the *belemnites.*

The order *Ammonoidea* includes all the cephalopods in which the suture is angulated, from the primitive clymenoids to the ammonitoids. Strictly speaking, the term "ammonite" is synonymous with "ammonitoid," but it is sometimes applied to all members of the order. The dominant Jurassic ammonites were derived from a parent stock which dates back to the Devonian. This stock was only one of those

which flourished in the Triassic, and it is much modified with the advent of the Jurassic. This modification seems to consist in a slight loss of complexity in the suture, the assumption of a high degree of external ornamentation, and the development of an extraordinary number of species.

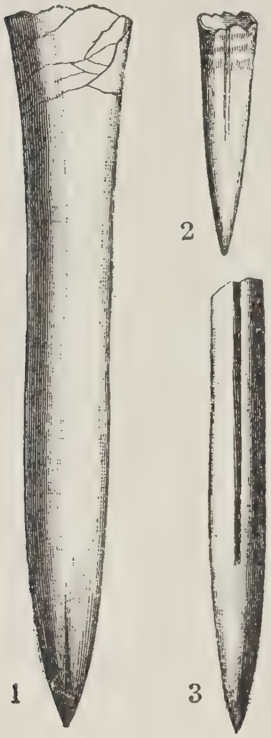

FIG. 155. LIASSIC AND JURASSIC BELEMNITES

1. *Belemnites paxillosus*, Liassic of Würtemberg; 2. *Belemnites acutus*, Liassic of Dorsetshire; 3. *Belemnites canaliculatus*, Lower Oölite of Würtemberg. *Reduced from Zittel.*

American Jurassic ammonites are insignificant in number when compared with the vast fauna of Europe. *Phylloceras*, *Haploceras*, and *Perisphinctes* are among the commonest genera.

BELEMNITES are related to the nautiloids and ammonites, but they form a shell of a very different character. Instead of being an external investment in which the animal lives, it consists of an elongated structure enclosed within the body to give rigidity to the creature. It is thought that belemnites developed from *Orthoceras* by the gradual surrounding of the shell by the animal. In this way the chambered cone of *Orthoceras* gradually became converted from an external to an internal structure. This change rendered useless the empty chambers of the original shell, which dwindled in consequence; at the same time greater strength was given to the structure by the formation of a thick layer of calcite on the outside. The final result was a solid cigar-shaped rod of calcite with a small conical cavity at the anterior end in which the dwarfed remnants of the original chambered cone remained. Belemnites existed in enormous numbers, as their skeletons (cigar fossils) are crowded in many layers of Jurassic rock. *Belemnites densus* is probably the best known American example. Numerous belemnites are found in the Jurassic rocks of British Columbia.

The ARTHROPODS, or invertebrates with jointed limbs, are

represented by numerous types, among which the ten-footed crustaceans, or *decapods*, and the dragon-flies are the most important. The decapods with long tails, of which the lobster is an example, are numerous in the fine-grained lithographic limestones of Bavaria, *e.g. Eryon*. The same formation has yielded many dragon-flies, of which *Petalia* will serve as an example.

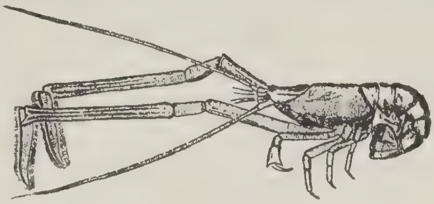

FIG. 156. JURASSIC DECAPOD
Mechochirus longimanus, from the lithographic limestone of Bavaria. About one-sixth natural size. *After Zittel.*

JURASSIC VERTEBRATES

FISH. The heterocercal ganoids of the Triassic are replaced in the Jurassic period by a related group, in which this archaic

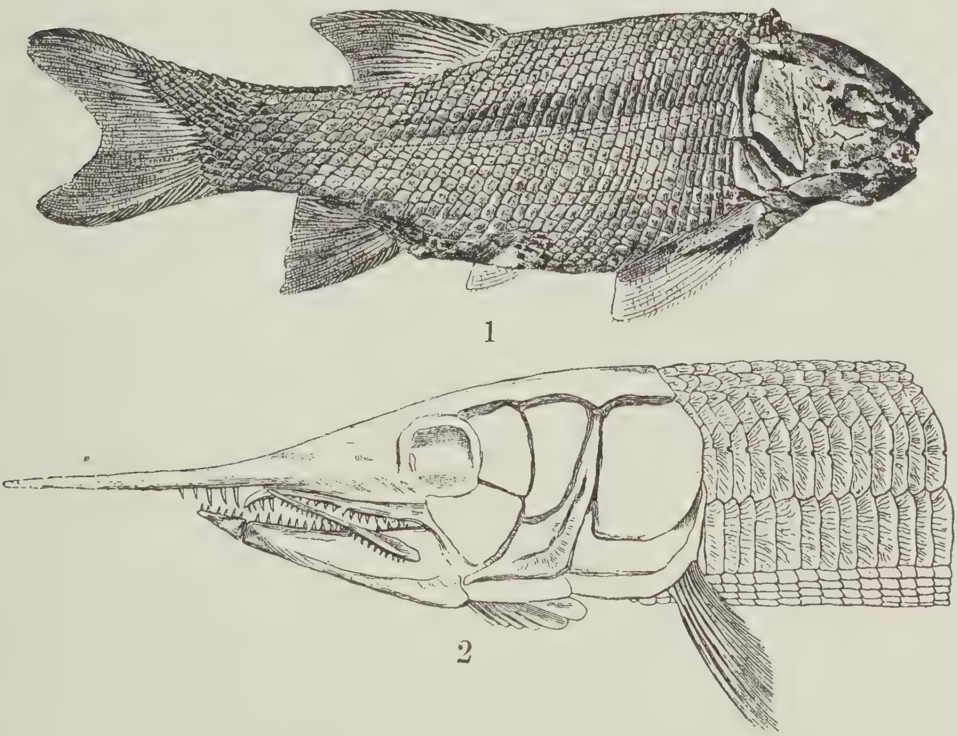

FIG. 157. SHINING-SCALED GANOIDS OF THE JURASSIC
1. *Lepidotus notopterus*, one-sixth natural size; 2. Head of *Aspidorhynchus acutirostris*. *After Zittel.*

form of tail is less pronounced, and in which the scales are generally thick and covered with a shining enamel. This type of fish by a thinning of the scales and the acquisition of a

bony skeleton gives rise to the modern bony fish. Between the shining-scaled ganoid and the bony fish there is no very sharp line of division. The great importance of these fish in the Jurassic justifies the citation of several examples as follows:

Dapedius. Thick scales and deep body.

Lepidotus. Thick scales and fusiform body. Large.

Aspidorhynchus. Thick rhomboidal scales and long, thin body.

Pachycormus. Thin overlapping scales and long body.

Leptolepis. Thin scales and partly bony skeleton. Shows the transition to the modern bony fish.

In addition to these ganoids there are many sharks, skates, rays, and chimeras.

Reptiles. Not only to the scientific worker, but to all persons of liberal education, the extraordinary reptilian life of the Mesozoic has appealed in the strongest terms. The grotesque shape, the varied habitat, and the gigantic proportions of these animals have all contributed to make them objects of interest and astonishment. Their influence is felt beyond the realm of pure science: it extends into the field of popular literature and has even invaded the realm of fiction. Reptiles dominated the time; they swam in the seas, lorded over the creatures of the land, infested the marshes, and even flew in the air.

Palæontologists believe that water-going reptiles did not arise directly from fish, but that they descended from land reptiles which, in search of food or to escape their enemies, gradually became accustomed to life in the water. This adaptation was manifested in the Permian, and became more pronounced in the Triassic. In the Jurassic seas water reptiles reached a high degree of development, and are represented by a number of diverse forms.

Ichthyosaurs (fish lizards) were the most abundant type. These creatures had a long, fish-like body, powerful tail, short neck, and four limbs in the form of paddles. In some cases they reached a length of ten metres. Many species are known from the Jurassic rocks of Europe, and to a less extent from America, Australia, and New Zealand.

Plesiosaurs resemble ichthyosaurs, but they are thought to have descended from a different stock. They rival the ichthyosaurs in size and are characterised by a long neck and a short tail. As the tail is not adapted for a swimming organ propulsion is effected by the paddles, which are relatively longer than in the ichthyosaurs. *Nothosaurus* of the Triassic was a forerunner of the plesiosaurs, which were numerous in the Jurassic and continue into the Cretaceous.

Crocodiles are represented by a number of primitive forms with long thin snouts (*teleosaurs*), and towards the close of the period by smaller forms with broad snouts. Sea turtles are known before the close of the Jurassic, but they attain a greater prominence in later ages.

Many forms of land reptiles are known, but the greatest interest is attached to the group named *Dinosauria* or *dinosaurs*. These creatures varied in size from that of a cat to proportions truly gigantic. They all had short, stout bodies, long tails, and legs which were very long for reptiles. Instead of *crawling*, as most reptiles do, they *ran* or *walked*, sometimes on all-fours and sometimes on the hind limbs only. Anatomists recognise many distinctive features in dinosaurs, but probably the most characteristic is this method of progression.

Many dinosaurs have been recorded as occurring in the Jurassic rocks of North America, but the strata containing them (Morrison formation) are now believed to be of Cretaceous age. No dinosaurian remains in rocks of certain Jurassic age are known in North America.

Dinosaurs are extremely varied and have been classified in different ways by different authors; in general, it may be said that there are three types—carnivorous, amphibious, and beaked.

Carnivorous dinosaurs have large heads, short necks, clawed digits, long powerful hind limbs and much shorter fore limbs, and sharp-pointed serrated teeth. This type of dinosaur is much more important in the Cretaceous, but complete skeletons of small forms and numerous fragmentary remains have been found in the Jurassic rocks of Europe.

Amphibious dinosaurs, in all probability, were numerous in North America during the Jurassic, but owing to the unfavourable conditions of preservation their remains have

not been found. Their abrupt appearance at the very base of the Cretaceous leads to the above inference, but in view of the actual evidence we must regard them as essentially Lower Cretaceous fossils.

Beaked dinosaurs, despite their great size, are very bird-like in many points of their anatomy, particularly in the presence of a horny sheath in the front of the jaws. This is a large group of dinosaurs of diverse shape and varied habit. Although of smaller size than the giant amphibious forms, they reach huge proportions and are remarkable in some cases

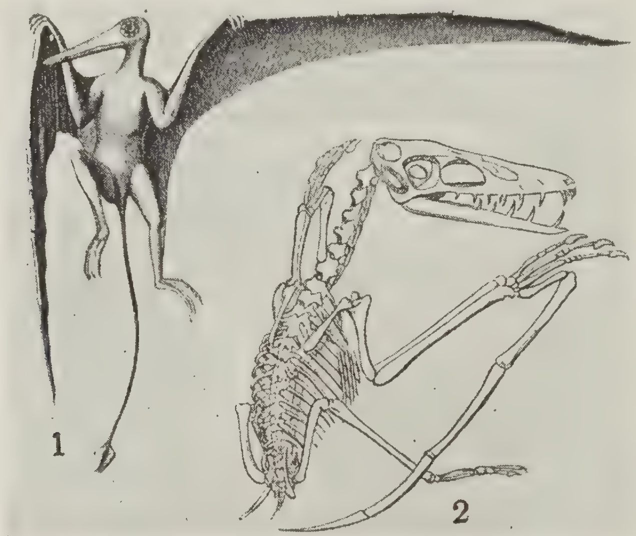

FIG. 158. MESOZOIC FLYING REPTILES

1. *Rhamphorhynchus*, Jurassic, one-seventh size; 2. *Scaphognathus crassirostris*, Jurassic. Reduced.

for the peculiar shape of the body and in others for the extraordinary defensive armour. *Scelidosaurus* is an unarmoured form and *Omosaurus* an armoured type from the Jurassic of Europe.

Flying reptiles are remarkable creatures which appeared at the beginning of the Jurassic and continued into the Cretaceous period with very little essential change. Large and small forms are known, but all are distinguished by a great extension of the little finger, which served as a support for a flap of skin stretched between the fore limb and the side of the body. This wing-like structure served as an organ of flight, but it is not to be compared with the true wing of the

bird. These animals are true reptiles, but their bones are modified to secure lightness and thus assist the power of flight. *Dimorphodon* and *Rhamphorhynchus* are long-tailed forms of considerable size; *Pterodactylus* is a smaller form with a very short tail.

BIRDS. The earliest bird is known by two well-preserved skeletons from the lithographic limestone of Bavaria and by less perfect forms from the Jurassic strata of Wyoming. The European bird, *Archæopteryx*, is about the size of a crow and

FIG. 159. ARCHÆOPTERYX MACRURA, THE FIRST BIRD (JURASSIC)

differs from all modern birds in several particulars, all of which prove its descent from reptilian ancestors. Both the upper and the lower jaws are armed with numerous teeth, the tail is an elongated structure composed of many vertebræ, and the wing or modified fore limb carries three clawed digits.

MAMMALS. The *Mammalia*, the highest form of animal life, differ from the reptiles in numerous ways; they all possess warm blood, provide milk for the young, are more or less hairy, and have a more perfect circulatory system. Mammals are of much higher intelligence than reptiles, and their actions are controlled by an ability to lay plans, to track their prey, and to attack their enemies in the most vulnerable parts.

Reptiles exhibit none of these attributes, as their actions seem to consist of instinctive rushes only.

The most lowly of existing mammals are small egg-laying forms now living in Australia. These creatures, when young, have peculiar teeth which are shed in the adult. Teeth of a very similar character have been found in Triassic rocks, but whether these are really mammalian is open to question. In the Jurassic, however, both jaws and teeth are known, which leave little doubt that diminutive and very primitive mammals had made their appearance.

The living marsupials (kangaroos, opossums, etc.) are animals of higher organisation than those referred to in the last paragraph. Teeth and jaws of small creatures believed to be marsupials have been found in both Triassic and Jurassic rocks. The Triassic forms are reptile-like, but the Jurassic examples are more distinctly mammalian.

CHAPTER XIV

THE CRETACEOUS PERIOD

THIS great system receives its name from the fact that chalk (*creta*) is an important constituent of the strata where first studied in England and France. The inappropriateness of names founded on rock characteristics is again illustrated by the word "Cretaceous," for chalk beds are by no means constant members of the system. The Cretaceous rocks of Canada, for instance, are practically devoid of chalk, and even limestone is of rare occurrence.

The Cretaceous system is very complex, and the deposits of one locality are with difficulty compared with those of others. Geographical conditions varied greatly, not only in the different continents, but in different parts of the same continent. In Europe, for instance, two distinct areas of deposition are generally recognised, and some authors would increase the number to three. The strata are different in these basins, and the faunas, while showing a general parallelism, have distinctive characters in each area.

In England the earlier Cretaceous deposits in the southern shires are largely of freshwater origin, while in the north they are distinctly marine. Wider-spread marine conditions prevailed in the latter part of the period, but no very distinct division into Upper and Lower Cretaceous was suggested by the earlier studies of the English strata. On the Continent, however, such a division is much more apparent, and English geologists now recognise a formation of dark blue clay (Gault) as the base of the upper division. The Lower Cretaceous formations of Europe indicate mixed marine and continental conditions of sedimentation, while the Upper Cretaceous formations are distinctly marine and point to a very extensive flooding of the continent.

In North America, the break between the Lower and Upper Cretaceous is still more profound; indeed, it is so marked that American geologists separate the strata into two distinct

systems—Comanchian and Cretaceous—believing that the break is comparable in magnitude with those that separate the other great systems. While this subdivision is doubtless better in accord with the facts as revealed in North America, it seems inappropriate, nevertheless, to introduce a new systemic name for strata that are admittedly to be correlated with the Lower Cretaceous rocks of Europe. In this work we shall regard the lower series as "Lower Cretaceous," but in deference to the opinion of many eminent American geologists, the term "Comanchian" will also be employed.

This general discussion of the Cretaceous period cannot be concluded without reference to the English chalk. The "White Cliffs of Albion," famous in history and song, are composed of chalk of Upper Cretaceous age. This formation is the most conspicuous member of the Mesozoic strata of Europe, and is referred o as *The Chalk.* Nearly the whole of the Upper Cretaceous rocks of England belong to this series, which is divided into three subdivisions—the Lower, Middle, and Upper Chalk. The stone is composed of enormous numbers of the minute calcareous shells of *Protozoa* (foraminifers) mingled with fragments of the shells of other organisms. Nodules of flint are common, more particularly in the Upper Chalk. Such a formation could have been made only under typical marine conditions in a sea into which no sediments were being discharged.

PHYSICAL EVENTS OF THE CRETACEOUS IN NORTH AMERICA

We have seen that the whole of eastern North America remained land throughout the Jurassic period, and we may conclude that it suffered a large amount of dissection and erosion. The products of this erosion were carried out to sea and are still beneath the waters of the Atlantic. Even in Lower Cretaceous time the sea did not invade the present land area, but changes in the coast-line made possible the accumulation of continental deposits along the coastal region. Lower Cretaceous continental deposits are found more particularly in Maryland, Virginia, and Georgia.

At the same time continental deposits were formed in limited areas in the western states, more particularly in Colorado and Wyoming. These beds (Morrison formation) are of particular interest as they have revealed some of the most remarkable dinosaurs yet discovered.

Depression of the continent in Lower Cretaceous time, which permitted the advance of the sea and the deposition of marine deposits, occurred over a wide area in the southwestern states, Mexico, and Central America. This series of deposits is the Comanchian proper. Marine invasions also occurred on the Pacific border, in British Columbia, Oregon, Washington, and California.

Owing to the great importance and significance of the deposits of the Gulf region and Mexico, the local name, Comanchian, has been elevated to the dignity of a time-term of systemic rank, and is applied by American geologists to all Lower Cretaceous formations.

Throughout the world, the Upper Cretaceous is marked by one of the most extensive floodings of the continental areas known in geological history. In North America, the eastern border of the United States, the region surrounding the Gulf of Mexico, and a wide strip of the Pacific coastal region were submerged. In addition, and of still greater importance, was a depression of the interior continental region whereby the sea covered a wide belt of west-central North America from the Arctic ocean to the Gulf of Mexico.

In the extreme west of the continent, terrestrial disturbances were marked throughout the Cretaceous. The most important movement in the Lower Cretaceous was the elevation of a long strip of country extending from Alaska to Central America. The axis of elevation lay some distance east of the coast and passed through the central region of British Columbia. The elevation of this strip probably occasioned a downwarping on either side, and prepared the way for the advance of the Upper Cretaceous sea into the interior of the continent and over the region immediately bordering the Pacific.

Upper Cretaceous time continued to be a period of uplift and of volcanic activity in the Cordilleran region. Towards the close of the period the uplifting forces reached a climax

of intensity deserving the name *revolution*, which is applied only to terrestrial disturbances on the grandest scale.

In order to better understand the results of this revolution, it is advisable to review the history of the area affected. We have seen that in the early Cambrian a trough was formed to the east of the old Pre-cambrian lands which constituted the Pacific border of the continent. In this trough sedimentation

FIG. 160. SKETCH MAP OF NORTH AMERICA IN CRETACEOUS TIME

continued through nearly all the Palæozoic era. The sea partially withdrew in the Triassic, but returned in the Jurassic and Lower Cretaceous periods, adding to the great thickness of strata already formed in the Rocky Mountain geosyncline. The mid-continental sea of the Upper Cretaceous overlapped this region and still further increased the thickness of the sediments, which are not less than 50,000 feet and probably much more in total thickness.

It was this region, so long an area of sedimentation, that

was chiefly affected by the revolution at the close of the Cretaceous. A great thrust acting from the direction of the Pacific ocean threw the region into immense folds with a general north-west and south-east trend. These folded masses of rock were elevated to great heights, crumpled and broken; great faults developed in places; and immense masses were pushed, in some cases for miles, out of their original position. This great event is known as the *Laramide revolution*; it marks the birth of the Rocky mountains and the close of Mesozoic time.

In other parts of the world mountain-making forces were at work at the same time. The Appalachians of eastern North America were re-elevated, the Andes of South America were formed, and general elevation and mountain-building occurred in the Old World.

THE CRETACEOUS SYSTEM IN CANADA

In eastern Canada no Cretaceous strata, either continental or marine, are known. The Upper Cretaceous transgression which affected the eastern border region of the United States did not advance as far north as Canada.

In western Canada rocks of this age are of great importance: their description can be best given under the following four areas of distribution:

1. The Great Plains Area. The region occupied by the Cretaceous rocks in the prairie region of western Canada may be roughly defined as a great triangle, stretching along the international boundary for 750 miles from the centre of Manitoba to the foothills of the Rocky mountains and reaching an apex 1000 miles to the north-west in the south-east corner of Yukon territory. While Cretaceous strata were undoubtedly formed over the whole of this area, they do not form the surface rock throughout, as they have been covered by later formations to a limited extent. The chief of these areas of later rocks are in southern Saskatchewan and in western Alberta.

The greater part of the region is covered with a thick accumulation of glacial and post-glacial deposits which hides

the rocks except where deep river valleys have been cut through the soils or where the flanks of minor elevations have been eroded.

The rocks of this area were formed in the great shallow sea of Upper Cretaceous age which covered the heart of the continent. This sea was doubtless subject to many minor fluctuations which resulted in local deposits, and in its later stages, particularly in the western part, it passed into the condition of brackish and even freshwater lakes. Owing to the above facts and the scattered nature of the accessible exposures, it has not yet been possible to accurately correlate all the formations of this great region.

The Upper Cretaceous rocks of this area may be arranged in three divisions, erroneously but usually called "groups," above which lies a fourth division of less magnitude, as follows:

Edmonton formation.
Montana group.
Colorado group.
Dakota group.

The Dakota group in Canada is composed essentially of sandstone which is largely of freshwater origin. Exposures of the rock are of rather rare occurrence: the most typical are to be seen in the valleys of the rivers entering Lake Winnipegosis from the west. The stone is soft, incoherent, and of no particular value.

The Dakota, if it occurs, is so deeply buried under the later rocks all the way across the prairies that it is not seen again until brought to the surface by the folding which produced the foothills of the Rocky mountains. Exposures may be seen in the coal-mining districts of the foothills and in the lengthwise valley west of the first great range of mountains. At the Sweetgrass hills in Montana, just south of the international boundary, the Dakota group is much better exposed than at any point in Alberta. The section shows more than 500 feet of shale, sandy shale, and sandstone. The stone of the mountains differs greatly from that of Manitoba, as it is very hard and of green or bluish-green colour. At so great a distance from the Manitoba outcrops it is questionable

whether this formation is to be strictly correlated with the eastern sandstone.

The Colorado group is divisible into two formations—a lower (*Benton*) and an upper (*Niobrara*). Exposures occur in Manitoba and in the foothills, but across the Great Plains the formations are covered by the rocks of the Montana group. As revealed by bore-holes in southern Alberta the group is nearly 2000 feet thick, but the average is probably much less.

FIG. 161. SKETCH MAP SHOWING THE CRETACEOUS AND TERTIARY ROCKS OF THE GREAT PLAINS

Cretaceous, black; Mixed Cretaceous and Tertiary, dotted; Tertiary, the white areas within the black. The Cretaceous and Tertiary of British Columbia not shown.

The Benton formation consists essentially of shale and there is much soft clay carrying a large amount of colloidal silica. This material (bentonite) has a remarkable property of retaining water, which makes it a very valuable constituent of the soils derived from the decay of the Benton shales and other formations.

The Niobrara formation also is largely composed of clay or shale, but it is much more calcareous than the Benton shale and even contains thin layers of limestone in places. The formation is recognised with certainty only in the eastern exposures.

The areal extent of the Dakota and Colorado groups is insignificant when compared with that of the Montana group, which forms the surface rock over nearly the whole of the Cretaceous region of the Great Plains. There are two facies of Montana deposits: marine, and brackish to freshwater. In the eastern part of the region, the marine facies, *Pierre formation,* is alone developed, but in the west the brackish water deposits, *Belly River formation,* occur between an upper and a lower series of marine strata. The Pierre formation is mostly shale, and much of it presents the same colloidal properties as the Benton shale. The Belly River beds are composed of soft sandstones and shales.

The Edmonton formation is very similar to the Belly River in the character of its rocks, consisting of soft, incoherent sandstones, sandy shales, and shales. The formation overlies the upper marine beds of the Pierre over a considerable area in central Alberta.

The conditions of shallow and brackish water under which the Belly River and Edmonton beds were deposited favoured the formation of layers of coal. Owing to the relatively short lapse of time and the lack of severe terrestrial disturbances since the beds were formed, coal-forming has not proceeded beyond the earlier stages; in consequence, nearly all the coal is lignitic or sub-bituminous. At Lethbridge, however, the coal is of bituminous grade.

In the Belly River formation Dowling estimates that 33,192 square miles are underlaid by coal beds which contain a reserve of 223,358,000,000 metric tons. The principal mines are situated in the vicinity of Lethbridge, Alberta. The same authority estimates a maximum reserve of 800,958,000,000 metric tons and a more certain reserve of 383,697,000,000 metric tons in the Edmonton formation. The chief collieries are near Drumheller on the Red Deer river, near Edmonton, and in the foothills.

The importance of the colloidal clays has already been referred to. The water-holding clay soils (gumbo) owe their valuable property of retaining moisture to the hydrated silica derived from the decay of Benton and Pierre shales. These colloidal clays are not suitable for brick-making, but some of the upper non-colloidal clays of the Pierre

(Odanah) as well as the brackish water clays are used for this purpose.

Natural gas is another important product from the Cretaceous formations, more particularly of Alberta. The gas reservoirs are in the Dakota sandstone; they are tapped by deep holes through the overlying strata, more particularly at Medicine Hat and Bow island. Far to the north, on the Athabasca river, are the so-called tar-sands—sandstones of Dakota age highly impregnated with bitumen: they are thought to represent a future source of important industrial products.

2. The Rocky Mountain Area. We have seen that the Rocky Mountain geosyncline was an area of sedimentation in the Lower Cretaceous. The strata consist of an upper and a lower sandstone with coal-bearing measures between. The presence of beds of coal and fossil plants indicates that this series, the *Kootenay*, is of freshwater origin. The greatest thickness, nearly 4000 feet, is along the main axis of the Rocky mountains; eastward, the strata thin out rapidly and are overlapped by Upper Cretaceous rocks. The upraising of the mountains at the close of the Cretaceous affected all these rocks, but subsequent erosion has removed them from the summits of the ranges. Kootenay strata, therefore, are found to a limited extent in the foothills, but on a larger scale in the valleys between the more easterly ranges of the mountains.

The coal of the Kootenay formation is a high-grade bituminous, ranging to anthracite in places. Numerous fields occur in the long narrow valleys between the ranges; the most important is the Crowsnest field in British Columbia, in which the reserve is estimated at more than 56,000,000,000 metric tons, with a workable reserve of 23,000,000,000 metric tons. The centre of this field is Fernie, British Columbia. The more important coal-mining centres on the Alberta side of the boundary are at Coleman on the Crowsnest line, and at Bankhead on the main line of the Canadian Pacific Railway.

3. Interior Plateau Area of British Columbia. In the interior of British Columbia, between the Coast Range and the Columbia mountains, are many disconnected areas of coarse sediments of Cretaceous age; these are generally mixed with contemporaneous volcanic matter. In northern British Columbia coal fields occur in these areas.

4. Pacific Coast and Islands Area. Fossiliferous sandstones, shales, and conglomerates of Upper Cretaceous age constitute the *Queen Charlotte series*, which carries workable beds of coal on the islands and is known to occur elsewhere.

On the north-east side of Vancouver island and on the adjacent small islands of the Strait of Georgia, Upper Cretaceous sandstones and shales, the *Cowichan group*, are well exposed. Coal mines of considerable importance are worked in these rocks at Nanaimo, Comox, and other places in the vicinity. Excellent sandstone for building purposes is quarried on Gabriola, Saturna, and other islands of the Strait of Georgia.

LIFE OF THE CRETACEOUS

CRETACEOUS PLANTS

In Lower Cretaceous time the vegetation shows the same predominance of cycads that characterised the Jurassic period; in the upper division, however, the angiosperms, or higher flowering plants, begin to assert the supremacy they still enjoy. In late Lower Cretaceous time cycads and conifers began to wane and trees like the sassafras and poplar appeared. Before the close of the Upper Cretaceous the flora was distinctly of modern aspect, with species of birch, maple, oak, walnut, and many other familiar trees. With these plants were mingled species of magnolia, fig, and cinnamon, indicating a warmer climate.

The brackish water beds of western Canada have furnished the remains of a long list of plants: probably the most striking fossils are the large silicified trunks of a species of cypress which are common in the Edmonton formation of Alberta.

CRETACEOUS INVERTEBRATES

Protozoa reach a high degree of development, as the remains of these minute organisms form a large part of the Chalk of Europe. The more calcareous parts of the Niobrara formation of Manitoba contain numerous protozoans.

Sponges, both siliceous and calcareous, are common in the

Cretaceous of Europe, but in North America they are of less frequent occurrence. The flints of the English Chalk are formed by the accretion of dissolved silica derived from the spicules of siliceous sponges.

Corals are abundant in the Cretaceous rocks of some regions, but they are rare in Canada. The conditions under which the prevailing shales were deposited did not favour the life of corals.

Echinoderms are represented chiefly by sea urchins which show an advancing tendency to irregular form. The peculiar stemless *Uintacrinus* with remarkably long arms is a characteristic fossil of the Cretaceous of Kansas. *Hemiaster humphreysianus* is the only sea urchin from the Upper Cretaceous rocks of the Great Plains, and is of rare occurrence.

FIG. 162. CRETACEOUS CRINOID
Uintacrinus socialis. Much reduced.

Pelecypods are very numerous, and some peculiar forms are particularly characteristic of Cretaceous time: of these, *Hippurites* and related forms, with one valve extremely small and placed like a cover on the larger valve, are eminently Cretaceous. The commonest genera in the marine Cretaceous rocks of western Canada are *Arctica*, *Inoceramus*, *Gervillia*, *Pteria*, *Ostrea*, and *Liopistha*. The brackish water beds of the Belly River series are in places crowded with oysters: *Corbula* and *Corbicula* are also very abundant.

Gastropods are numerous and show a normal advance on the Jurassic type, but they present no especial features for general comment. *Anisomyon*, *Lunatia*, and *Anchura* are perhaps the commonest Canadian genera.

Cephalopods are represented by many belemnites and ammonites. The former require no particular mention, but

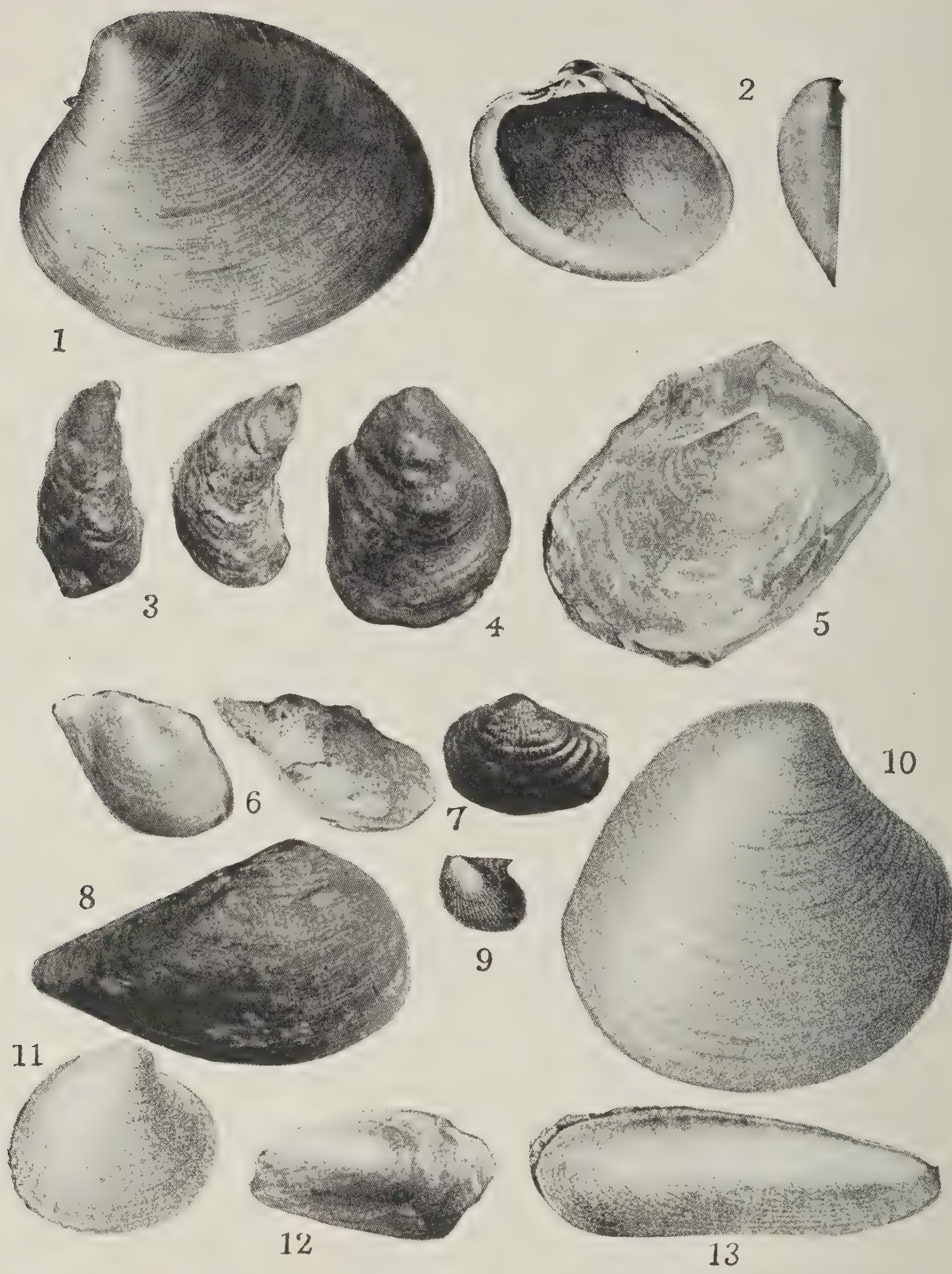

FIG. 163. CRETACEOUS PELECYPODS

1. *Arctica ovata alta*; 2. *Arctica ovata*; 3. *Ostrea subtrigonalis*; 4. *Ostrea glabra*; 5. *Inoceramus barabini*; 6. *Pteria linguifera*; 7. *Liopistha undata*; 8. *Corbula perangulata*; 9. *Pteria nebrascana*; 10. *Corbicula occidentalis*; 11. *Protocardia borealis*; 12. *Volsella meeki*; 13. *Modiola attenuata*. All figures six-sevenths natural size. *After Whiteaves, Meek and Hayden, and from original photographs.*

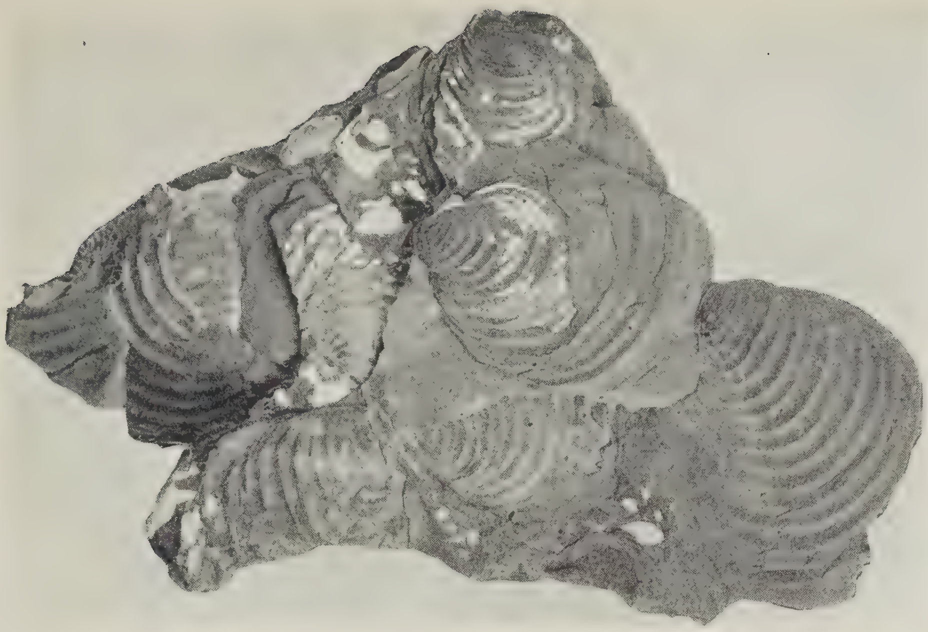

FIG. 164. CRETACEOUS PELECYPOD

Slab of red Cretaceous sandstone from the Red Deer river, Alberta, with *Inoceramus vanuxemi*. One-fourth natural size.

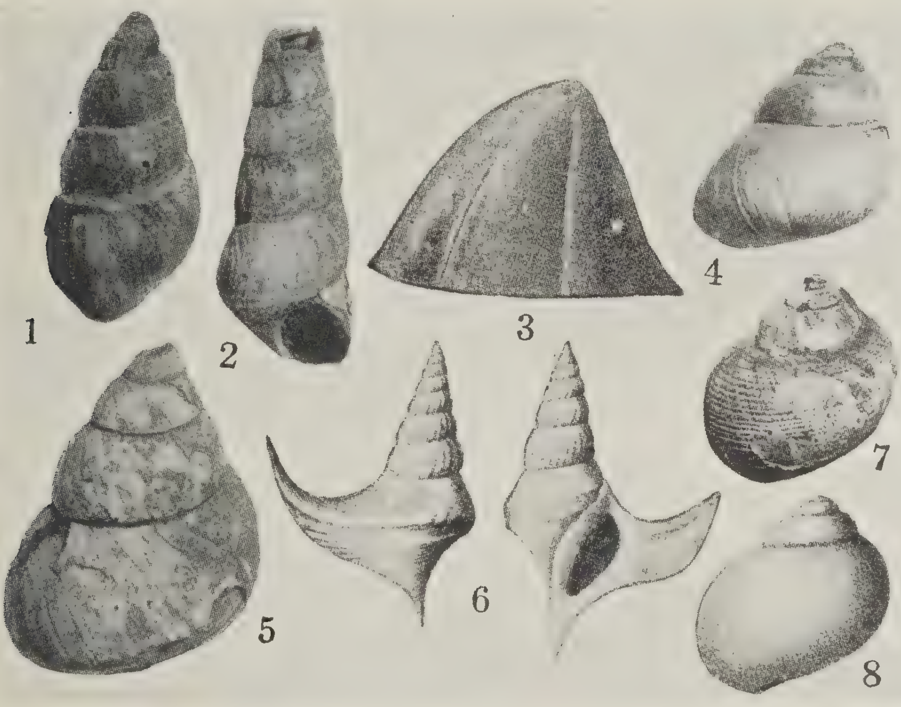

FIG. 165. CRETACEOUS GASTROPODS

1. *Campeloma producta* ; 2. *Melania insculpta* ; 3. *Anisomyon centrale* ; 4. *Viviparus leai*; 5. *Anchura americana* ; 6. *Vanikoropsis tuomeyana* ; 8. *Lunatia concinna*. All figures about natural size. *From Meek and Hayden and from photographs of species from western Canada.*

the latter show evidence of decadence. While many typical ammonites with closely coiled shell still survive, the senile condition of the race is indicated by the assumption of peculiar form. Instead of the typical coiled shell, we find straight (*Baculites*), hook-shaped (*Hamites*), open-coiled (*Crioceras*), turreted (*Turrilites*), and many other erratic forms. This tendency to strange shape seems to be the precursor of extinction, for no ammonites are known after the Cretaceous.

One of the commonest fossils of our western Cretaceous is the straight-shelled *Baculites*, of which several species are known. The fragments of this fossil are commonly mistaken for fish. A very large ammonite, *Placenticeras whitfieldi*, is also a common fossil in the Cretaceous of the plains. The Upper Cretaceous strata of Vancouver and Queen Charlotte islands have yielded a rich and varied ammonite fauna.

Arthropods are well represented and show a great increase in the broad-shelled decapods or crabs. These fossils are rare in the Montana group of the plains, but ten species are known from the Cowichan rocks of Vancouver island.

CRETACEOUS VERTEBRATES

Fish show a pronounced change in Cretaceous time, as the old type with skeleton of cartilage gradually gives place to the *teleosts* with true bony skeleton and thin, flexible, overlapping scales. In other words, the modern type of fish gains an ascendancy over the typical Mesozoic type, and is represented, before the close of the period, by such familiar fish as salmon, herring, and other common forms. Some of the Cretaceous fish were of great size and predaceous habits: *Portheus* was twelve to fifteen feet in length and the mouth was armed with a truly formidable series of teeth. Sharks were still numerous and were closely related to modern types.

Reptiles. The Cretaceous system equals and probably exceeds the Jurassic in the number and variety of the reptilian remains. The inclusion of the famous Morrison beds of Wyoming and Colorado in the Cretaceous transfers to this system many of the largest and best known dinosaurs which were formerly believed to be of Jurassic age.

Ichthyosaurs resembling those of the Jurassic occur, but

less frequently, in the Lower Cretaceous: they do not survive the middle of the Upper Cretaceous.

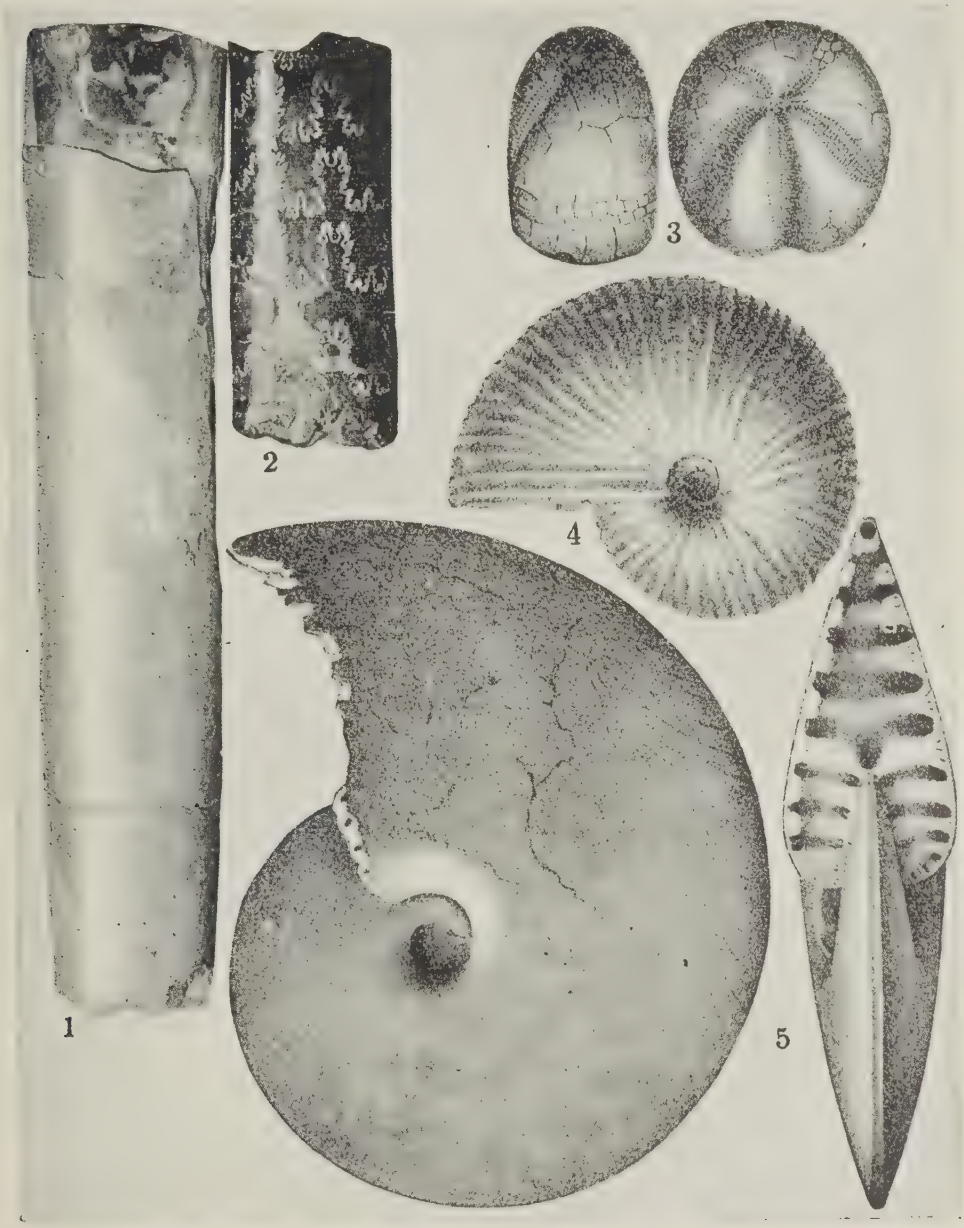

FIG. 166. CRETACEOUS ECHINIDS AND CEPHALOPODS

Baculites ovatus, specimen from Peace river with the outer shell; 2. *Baculites sp.* with the outer shell removed showing the sutures; 3. *Hemiaster humphreysianus*; 4. *Scaphites subglobosus*; 5. *Placenticeras whitfieldi*. Reduced. *After Whiteaves and Meek.*

Plesiosaurs are more abundant in Cretaceous than in Jurassic time: they reach their maximum development in the later part of the period and survive until its close. Some of

these creatures were of great size: the head of the largest form known was about five feet long, and the smallest species was fully ten feet in length. *Elasmosaurus platyurus*, the

FIG. 167. UPPER CRETACEOUS PLESIOSAUR
Elasmosaurus platyurus with an ichthyosaur, flying reptiles, and the diving bird *Hesperornis*. *From Williston, "Water Reptiles, Past and Present."*

longest-necked plesiosaur, shows the following proportions: head, two feet; neck, twenty-three feet; body, nine feet; tail, seven feet.

FIG. 168. CRETACEOUS MOSASAUR
Thylosaurus dyspelor, one-nineteenth natural size. *From "Memoirs of the American Museum of Natural History."*

While the remains of plesiosaurs are not particularly numerous they have, nevertheless, been recorded from all parts of the world where marine Cretaceous strata occur. *Cimoliosaurus magnus* from the Belly River formation of Alberta is the only Canadian example.

A new type of aquatic reptile appeared in the Upper Cretaceous and existed in large numbers in many parts of the world. Thousands of specimens have been obtained from the chalk beds of Kansas alone. These creatures, known as *mosasaurs*, were very long-bodied, almost snake-like, and were provided with four "paddles" or modified limbs differing greatly from those of ichthyosaurs and plesiosaurs. The structure of the skeleton is very peculiar, and indicates a totally different ancestry from that of the other aquatic reptiles. They were not unlike the mythical sea-serpent. In size the known forms range from eight to forty feet in length. *Platecarpus* is one of the best known American genera.

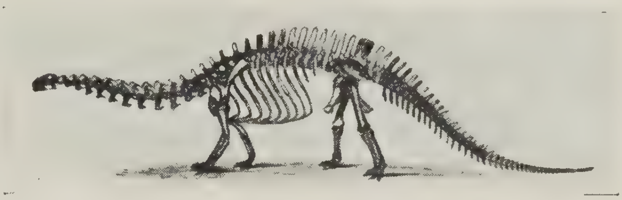

FIG. 169. THE GREAT AMPHIBIOUS DINOSAUR
Brontosaurus excelsus.

Among the water reptiles, turtles and crocodiles played an important rôle. Several very large turtles occur in the Belly River beds of Alberta, also a few crocodiles.

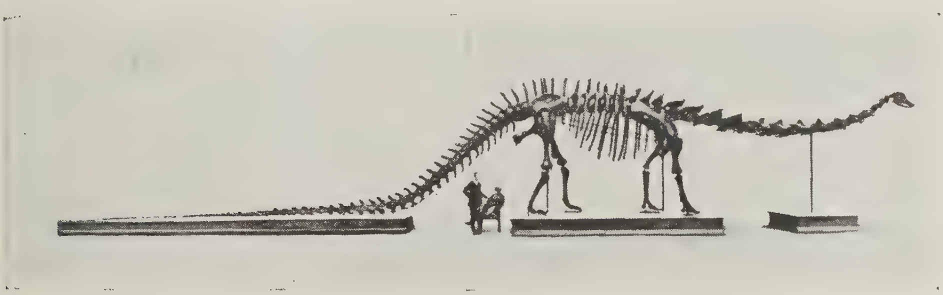

FIG. 170. THE GREAT AMPHIBIOUS DINOSAUR
Diplodocus carnegii, eighty-seven feet long.

The dinosaurs, or great land reptiles, were even more numerous and diversified than in the Jurassic: they may be conveniently considered as belonging to three general types, as follows:

"*Amphibious dinosaurs* were the Giant Reptiles *par excellence*, for all of them were of enormous size, and some were by far the largest of all four-footed animals, exceeded in bulk only by the modern whales. In contrast to the carnivorous

X

dinosaurs these are quadrupedal, with very small head, blunt teeth, long giraffe-like neck, elephantine body and limbs, long

FIG. 171. CRETACEOUS CARNIVOROUS DINOSAUR
Gorgosaurus libratus. From Belly River formation of Alberta. About 1–100 natural size. *After Lambe.*

massive tail prolonged at the end into a whiplash as in the lizards. Like the elephant, they had five short toes on each foot, probably buried in life in a soft pad, but the inner digits

FIG. 172. CRETACEOUS CARNIVOROUS DINOSAUR
Head of *Tyrannosaurus rex.* About one-twentieth natural size. *By permission of the American Museum of Natural History.*

bear large claws, blunt like those of turtles, one in the fore foot, three in the hind foot."[1]

[1] "Dinosaurs," W. D. Matthew, *American Museum of Natural History.*

Brontosaurus, a form from the Lower Cretaceous of North America, measuring sixty-six feet eight inches in length, is one of the best known of these giant reptiles. A skeleton of *Diplodocus* in the Carnegie Museum at Pittsburg is eighty-seven feet in length, but indicates an animal of somewhat more

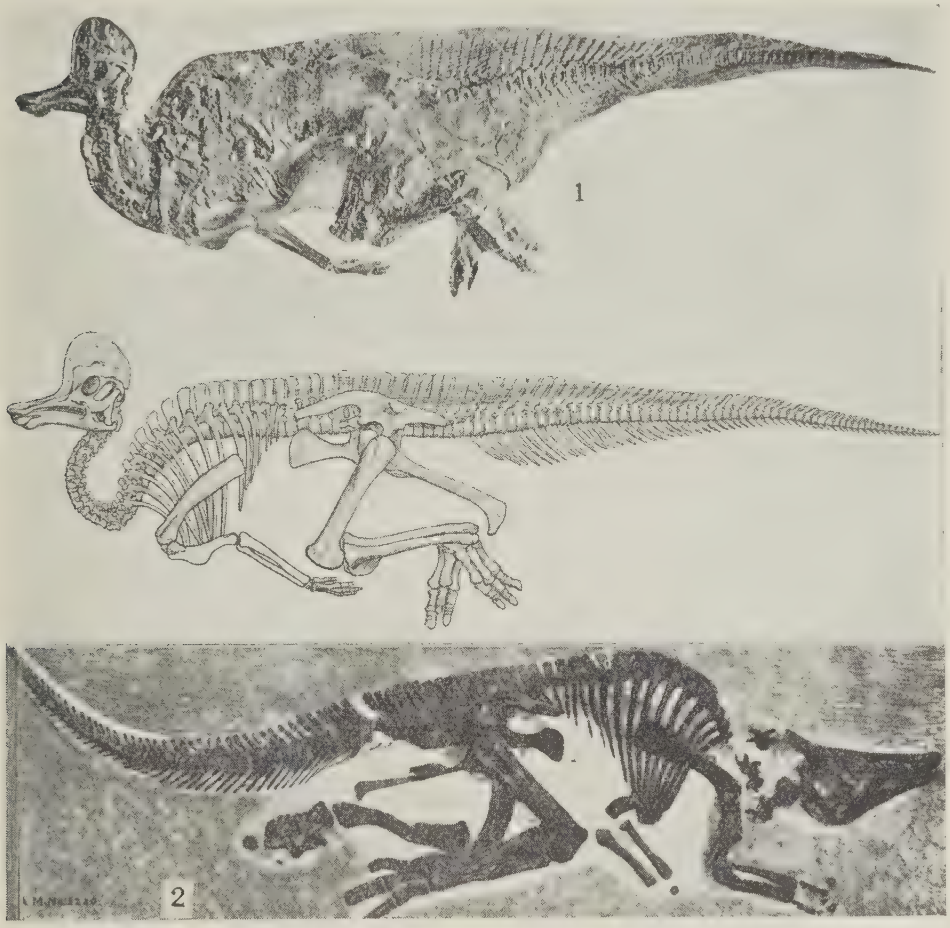

FIG. 173. CRETACEOUS TRACHODONT DINOSAURS

1. *Corythosaurus casuarius*, photograph and drawing of the specimen in the American Museum of Natural History, New York. 2. *Saurolophus osborni*, Edmonton formation, Alberta. Photograph of specimen in American Museum of Natural History, New York. No. 1 about one-sixtieth natural size, No. 2 about one-fifty-eighth natural size. *After Brown, by permission of the American Museum of Natural History.*

slender proportions than Brontosaurus. Even larger forms are known to occur in the Cretaceous strata of Kenia in Africa.

The general features of *carnivorous dinosaurs* have been briefly described on page 301: in the Cretaceous period they reached remarkable dimensions and were doubtless the lords of creation. The largest known carnivorous dinosaur, well

named *Tyrannosaurus rex* (tyrant saurian king), was forty-seven feet long; standing in erect position, it was eighteen to twenty feet high. The head, four feet three inches long,

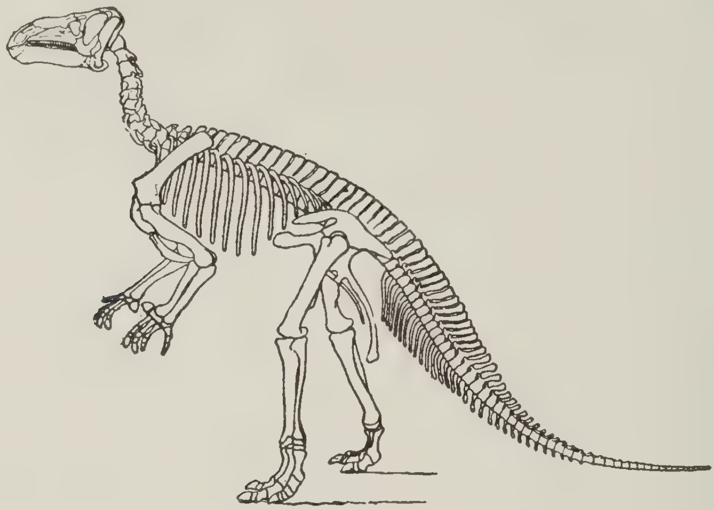

FIG. 174. EUROPEAN CRETACEOUS BEAKED DINOSAUR
Iguanodon bernissartensis. About 1–110th natural size. *After Marsh.*

was armed with a formidable array of sharp pointed teeth from three to six inches in length. A related form, *Gorgosaurus*, from the Belly River beds of Alberta, is twenty-nine feet long and shows the characteristic diminution of the fore limbs to an extreme degree.

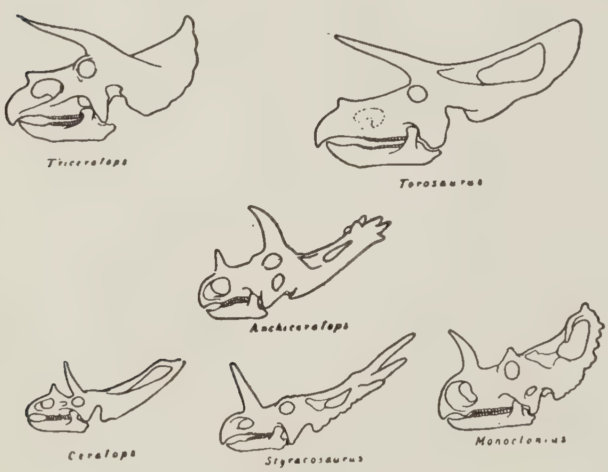

FIG. 175. CRETACEOUS HORNED DINOSAURS
Heads of different genera. Greatly reduced. *From Matthew,* "Dinosaurs," *American Museum of Natural History.*

The *beaked dinosaurs* probably include the most remarkable animals in all history; known first from the Jurassic, they reach a wonderful development in the Cretaceous. Of the unarmoured kinds, *Iguanodon* from Belgium and the *trachodonts* of North America are known by many complete skeletons. Trachodont dinosaurs are so named on account of the peculiar

teeth, which are numerous and set closely together to form a sort of inclined mashing surface. They are also known as "duck-billed dinosaurs" in reference to the shape of the predentary bones, which resemble the bill of a duck. In erect position these animals reached a height of about sixteen feet: they are characteristic of Upper Cretaceous time, and continued until its close.

Both the Edmonton and Belly River beds of Alberta, where exposed in the valley of the Red Deer river, have

FIG. 176. CRETACEOUS HORNED DINOSAURS
Monoclonius amid typical Belly River vegetation. *From Deckert and Brown, "American Museum of Natural History."*

yielded many skeletons of these dinosaurs. Fragmentary bones may be collected in places literally by the wagon load. *Saurolophus*, with a spine at the back of the head, is of frequent occurrence in the Edmonton beds, and *Corythosaurus*, with a plate-like crest on the skull, is a typical Belly River example.

The development of armour in the beaked, vegetable-feeding dinosaurs is the natural outcome of the attacks of the giant carnivorous forms. Many and varied are the methods of defence and extraordinary the results, as these creatures are among the most grotesque animals known. *Stegosaurus*, a Lower Cretaceous form contemporary with *Brontosaurus*,

FIG. 177. CRETACEOUS ARMOURED DINOSAUR

Stegosaurus ungulatus. Restoration in the Peabody Museum, Yale University. About one-fiftieth natural size. *After Lull.*

was armed by a double row of great plates along the back: the largest of these plates was more than two feet in length. The *Ceratopsia* include a number of extraordinary animals in which the skull was armed with horns and extended backwards into a great fringe around the neck. The Belly River formation of Alberta has yielded a number of forms, *Ceratops*, *Styracosaurus*, *Centrosaurus*, and *Monoclonius*, in which the fringe is pierced by openings or drawn out into finger-like extensions. The Edmonton formation yields a similar form, *Anchiceratops*; and the best known animal of all, *Triceratops*, with a solid fringe and three horns, occurs in the uppermost Cretaceous beds of Wyoming.

A different type of armour is seen in *Ankylosaurus*, a huge, flat-bodied creature covered from the snout to the end of the tail with great bony plates set closely together: it has been described as "the most ponderous animated citadel that the world has ever seen." This wonderful animal was made known to science chiefly by discoveries in the Edmonton formation of Alberta.

Birds. Two peculiar birds have been found in the Cretaceous of North America: one, *Hesperornis*, was a large wingless diving bird, reptile-like, with teeth except in the front of the upper jaw; the other, *Ichthyornis*, was smaller, with similar dentition, but with large wings and a carinate breast.

Mammals. Small archaic mammals resembling those of the Jurassic are known from Cretaceous rocks, but the ascendancy of this type of life is yet to come.

During Cretaceous time the conditions of our prairie region must have been as different as possible from those now prevailing. Instead of the bare plains with severe winters there were great forests like those of Pennsylvania or Alabama, suggesting a warm climate; and the inhabitants of the region, the grotesque and sometimes gigantic reptiles, dragging their length among the marsh grasses of the lagoons or springing, kangaroo-like, through the drier openings in the forest must have been even more different from anything Canadian of the present day. It was the triumphant time of the cold-blooded, egg-laying animals, when bulk and brute force ruled the world instead of brains.

CHAPTER XV

SUMMARY OF THE MESOZOIC ERA

Having reviewed the march of events and the evolution of life through the periods of the Mesozoic, we are now in a position to form a conception of the era as a whole.

The Mesozoic was ushered in by one revolution, the Appalachian, and brought to a close by another, the Laramide. Throughout the era there was much terrestrial disturbance, mountain-building, and volcanic activity. The strata formed during the time are very diversified, of different facies, and usually local in development.

FIG. 178. CRETACEOUS TURTLE
Aspideretes foveatus from the Cretaceous of Alberta. About one-sixth size. *From Hay, "Fossil Turtles of North America."*

In North America nearly the whole of Mesozoic history was written in the western half of the continent; in Canada this is even more striking, for, with the exception of a small area of Triassic rocks in Nova Scotia, there are no strata of this age east of Manitoba.

Coal was formed in large amounts in Mesozoic time; nearly all the coal of western Canada is derived from Cretaceous rocks, and it is obtained from the Cretaceous and other systems of the Mesozoic in different parts of the world.

The Mesozoic, as the name implies, was the time of "middle life"—the time between the archaic Palæozoic and the type of life now existing. Although the Mesozoic life evolved from that of the Palæozoic and is not separated from it by a break of the nature of a catastrophe, there is, nevertheless, a very great difference in the life of the two eras. Brachiopods ruled

among the shell fish of the Palæozoic, molluscs took their place in the Mesozoic; nautiloid cephalopods characterise the Palæozoic, ammonites succeeded them in the Mesozoic; cystids and blastoids and stony-vaulted sea lilies predominate in the Palæozoic, in the Mesozoic the two former groups disappear and the last is replaced by a type of crinoid with soft crown; the vascular cryptogams give place to the gymnosperms, and the armour-plated fish yield to the ganoids.

FIG. 179. CRETACEOUS WADING BIRD
Hesperornis regalis. One-twentieth natural size. *After Marsh.*

Above all else, however, the Mesozoic is unique in the number, diverse form, and great size of its reptiles: it is the Age of Reptiles.

Negatively the Mesozoic may be distinguished from the Palæozoic by the absence of trilobites, graptolites, blastoids, cystids, stromatoporoids, and armour-plated fish; positively it is marked by the presence of reptiles, ammonites, belemnites, and cycads.

Towards the end of the Mesozoic many organic changes took place, and the forerunners of the great life of the next era began to appear.

CHAPTER XVI

THE CENOZOIC ERA—THE TERTIARY PERIOD

THE Cenozoic era, or time of Recent Life, covers the history of the world from the close of the Mesozoic to the present. The early geologists applied the name *Tertiary* to all the rocks formed between the close of the Mesozoic and the opening of Recent time, as they were believed to represent the *third* great system. Later the term *Quaternary* was introduced to include the Recent and the time immediately preceding it. Authors are not yet agreed as to the exact way in which these old terms should be used in the light of modern knowledge. The classification adopted for this book is indicated in the table on page 331.

We have seen that a profound disturbance, the Laramide revolution, marked the close of the Mesozoic and resulted in great elevations of the lands in many parts of the world. Before the seas of the new era could advance, the rejuvenated continents must have been reduced by erosion or depressed by terrestrial movements. Time is required for these changes to be brought about, and an unrecorded interval is indicated by the fact that the Tertiary strata nearly everywhere rest with marked unconformity on the underlying rocks. This gap, however, is by no means so profound as was formerly believed, for rocks have been found showing an intermingling of Cretaceous and early Tertiary fossils. Also, where marine evidence fails, the story of the interval is revealed by strata of freshwater origin.

The Tertiary rocks of England rest unconformably on the Chalk, which had suffered profound erosion in the interval; on the other hand, the Tertiary strata of southern Europe cannot be sharply defined from the underlying Cretaceous. Freshwater Tertiary strata, in Canada and the United States, fade imperceptibly through brackish water deposits into the marine Cretaceous rocks.

The prevailing high lands at the opening of the Tertiary naturally resulted in a separation of the waters; later, when marine transgressions occurred, Tertiary deposits were made in isolated basins resulting in great diversity in the character of the rocks and in their organic remains. This local character of Tertiary formations is further increased by the important part played by fresh water in building up the strata.

Tertiary rocks, except where affected by mountain-making forces, are generally soft and incoherent, approximately horizontal, and charged with fossils in a relatively fresh and unaltered condition.

With the Tertiary period began the type of life now existing. Very early in the period appeared some species of molluscs which inhabit the present seas, and as time went on more and more of existing species were evolved. On this basis the pioneers of Tertiary geology divided the period into three epochs—*Eocene* (dawn of recent), *Miocene* (less recent), and *Pliocene* (more recent). Subsequent investigations have made it advisable to increase the number of epochs as indicated in the following table, which is taken from Pirrson and Schuchert's *Textbook of Geology*.

CLASSIFICATION OF THE TERTIARY PERIOD

Period		Epoch	Life
Tertiary	Neogene	Pliocene	90 to 100 per cent. of living molluscs
		Miocene	20 to 40 per cent. of living molluscs
	Paleogene	Oligocene	10 to 15 per cent. of living molluscs
		Eocene	1 to 5 per cent. of living molluscs
		Paleocene	Practically no living molluscs

During Tertiary time the present distribution of land and water was developed; in other words, geography as we know it to-day was established. During this time great terrestrial disturbances took place and many of the great mountain systems of the world received their final uplift, *e.g.* the

Pyrenees, the Alps, the Rockies, and the Himalayas. Vast quantities of molten matter were ejected from the interior of the earth, and masses of lava hundreds of feet in thickness were distributed over thousands of square miles of territory in many parts of the world.

While most marine Tertiary rocks are very local in character, formations of wide distribution were formed in a sea that extended across southern Europe, Asia Minor, and eastward to Burma and the Indian ocean. In Eocene time a limestone formation filled with vast numbers of the protozoan *Nummulites* was formed in this sea. As evidence of the profound changes of Tertiary time, this Nummulite limestone is found at an elevation of 10,000 feet above the sea in the Alps, 11,000 in the Pyrenees, and 19,000 in the Himalayas.

The great terrestrial changes of the Tertiary, or other causes of which we have no knowledge, seem to have produced remarkable variations in climate, especially in the northern hemisphere. Early Eocene time was temperate, but later in this epoch the climate became tropical into high latitudes and continued to be at least sub-tropical during the Miocene, as forests of this age flourished as far north as Spitzbergen. With the Pliocene the temperature fell in the northern hemisphere, and by its close it had become so cold that ice and snow covered vast areas extending well into the temperate zone. This refrigeration was coincident with the stupendous uplifting of mountain ranges which marked the Pliocene: the two events, mountain-making and refrigeration, brought the Tertiary period to a close.

PHYSICAL EVENTS OF THE TERTIARY IN NORTH AMERICA

The visible record of Tertiary events in North America, as in other parts of the world, is found only to a limited extent in strata of marine origin. The period opened with an elevated continent; in consequence, most of the marine deposits are still under the sea. At no time did oceanic waters cover more than a very small fraction of the present land area, and these invasions were confined to comparatively narrow strips along

the Atlantic and Pacific oceans and the Gulf of Mexico. In the interior of the continent, however, freshwater deposits on an extensive scale have preserved a record of physical events and of organic evolution. These freshwater deposits are extensively developed in the Western States and Canada: some authorities believe them to be of lacustrine or lake origin, while others regard them as flood-plain accumulations from rivers. Tertiary history is also recorded in great masses of volcanic rock, in displaced strata, and in profound erosion.

An interval of comparative quiet followed the Laramide revolution, and freshwater deposits of Paleocene age were made in the western continental region in isolated basins from Mexico to Canada. In early Eocene time the upthrust of the Laramide revolution was renewed in the Cordilleran region, and was accompanied by much volcanic activity. A long period of erosion and local accumulation of strata followed during the Eocene and early Oligocene. Marine overlaps occurred during this period of erosion, and Eocene strata were deposited along the southern Atlantic border in Maryland, Delaware, and Virginia; to a greater extent around the Gulf of Mexico; and in limited strips in California, Oregon and Washington, extending into Canada in the vicinity of Vancouver.

With Middle Miocene time crustal disturbances began again on a grand scale; pre-existing mountain ranges were elevated, new mountains formed, and vast quantities of molten rock ejected. The Pacific region was most seriously affected by this renewed activity. Volcanoes poured out ashes and lava along the whole Pacific border from Central America to Alaska: in the basin of the Columbia river alone, lava flows covered more than 200,000 square miles to a depth of at least 4000 feet. It is thought that a land barrier which had formerly bridged the Atlantic by way of Greenland, Iceland, and the Faroe islands broke down at this time, permitting the cold waters of the Arctic to advance down the eastern American coast. These northern disturbances were accompanied by tremendous flows of lava, of which the Giant's Causeway of Ireland is a remarkable example.

During Oligocene and Miocene time freshwater strata continued to be formed in the western continental region, and

oceanic overlaps occurred along the Atlantic, Gulf, and Pacific borders. In the Atlantic and Gulf areas of deposition numerous local formations of Oligocene and Lower Miocene age rest unconformably on the Eocene. The profound disturbances of Middle Miocene time are indicated by the practical absence of rocks of that age and the strong unconformity between the strata of the Lower and Upper Miocene.

Miocene marine overlaps occurred in the Pacific border region: strata of this age in California show the same evidence of a great disturbance about the middle of the epoch. On the British Columbia and Alaska coasts there is no certain evidence of marine deposits until late in Miocene time.

The Pliocene was a period of great elevation in the Cordilleran region and of extensive volcanic activity: then appeared the great series of volcanoes, Ranier, Shasta, Baker and many others, which continued active into later time. Eastern North America also was elevated, and the continent assumed the general geographical outline it still shows.

Marine deposits of the Pliocene are scattered and of little extent: most of the Pliocene accumulations are still under the sea.

THE TERTIARY SYSTEM IN CANADA

Evidences of marine transgression in eastern Canada are doubtful, but the march of events is recorded in extensive erosion and changes of level. Continental deposits, consisting of older rock decayed *in situ* and coarse sands and gravel, occur sparingly in the maritime provinces.

The withdrawal of the Cretaceous seas from the region of the Great Plains after the Laramide revolution made land of the sea floor over the greater part of the area. This withdrawal, being gradual, resulted in a freshening of the water that remained in restricted areas towards the close of the Cretaceous. In consequence, the latest Cretaceous deposits are of brackish or even freshwater origin. We have seen that in central Alberta a large area was covered by these residual waters, in which the brackish-water Edmonton formation was deposited. In southern Saskatchewan was another such

basin, in which somewhat later Cretaceous strata (Lance?) were deposited in waters probably fresher than those of the Edmonton basin.

With the opening of the Paleocene, the waters of both these basins had become quite fresh and deposits of sands and shales were made on an extensive scale. In Alberta we have the *Paskapoo* formation conformably overlying the Edmonton, and in southern Saskatchewan the *Estevan beds* (Fort Union formation of American geologists) similarly related to the Lance.

The Paskapoo sandstones are quarried in the vicinity of Calgary and at other points for building purposes. Both Paskapoo and Estevan shales are used for brick and tile-making, and numerous workable coal seams occur in the latter formation in the Estevan, Wood Mountain, and Willow-bunch districts of southern Saskatchewan. The coal is a soft lignite: its use has hitherto been restricted by a tendency to disintegration on storage or transportation, but it is hoped that its use at a distance will be made possible by a process of briquetting.

West of the main Tertiary area of southern Saskatchewan, in the Cypress hills, conglomerates, sandstones, and clays of Oligocene age unconformably overlie the Paleocene deposits.

In the time of comparative quiescence following the Laramide revolution, continental deposits doubtless accumulated in the intermontane region of British Columbia, but subsequent erosion and volcanic activity have obscured the record to a great extent. In the vicinity of Kamloops are beds of sandstone, conglomerate and shale of Eocene age, the *Coldwater group*. These beds were upturned and eroded before the extrusion of the late Tertiary volcanics, thus bearing evidence to the general deformation of the region in Miocene time. The Coldwater beds are by no means negligible, as their thickness has been estimated at 5000 feet: this mass of debris bears witness to the large amount of erosion accomplished during the Eocene.

Oligocene time was marked in this region by extensive extrusions of basalt from fissures. Daly thinks that these great masses of igneous rock interfered with the drainage and that basins were formed in which freshwater muds and

sands accumulated during the Oligocene and possibly also the Miocene (Tranquille group). The igneous rocks (Kamloops volcanic group of Drysdale) are estimated to have had originally an average thickness of 3000 feet. Volcanic rocks of the Oligocene and Miocene occur extensively throughout the interior region of British Columbia, and are largely responsible for the introduction of the gold, silver, and copper ores of the mining regions of the southern part of the province. Coals of this age are mined at Princeton and Nicola.

On the Pacific coast, the Eocene marine overlap of Oregon and Washington extended into the estuary of the Frazer river. Sediments were formed which are in part of marine

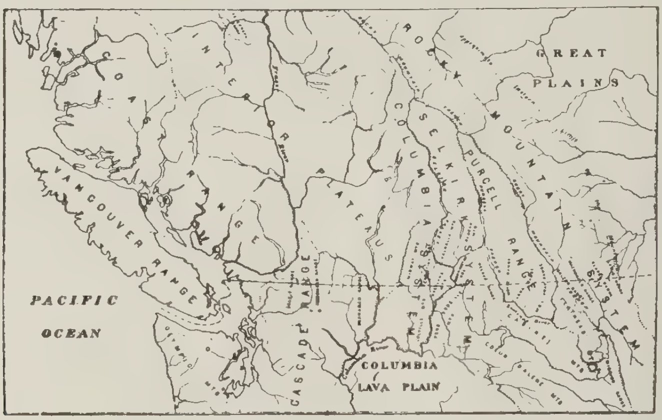

FIG. 180. MAP SHOWING THE NATURAL SUBDIVISIONS OF SOUTHERN BRITISH COLUMBIA
After Daly.

and in part of freshwater origin. The thickness of these deposits (Puget beds) must have been very great, for the strata, evidently a mere remnant, exposed along the lower part of the Frazer river are at least 3000 feet thick.

Farther north, sedimentary deposits of Tertiary age are of little extent and not well understood. Undoubted marine fossiliferous strata of Miocene age occur on Graham island, and formations on Vancouver island are likewise thought to belong to this epoch. Tertiary volcanics are of common occurrence in Vancouver and Queen Charlotte islands and northward into the islands of Alaska.

The great uplift of Pliocene times is thought to have elevated the whole Cordilleran region of British Columbia to heights differing greatly in different parts, but reaching

maxima of 2000 to 4000 feet. By this elevation the rivers were rejuvenated and a new cycle of erosion inaugurated which has extended to the present time.

LIFE OF THE TERTIARY

With the close of the Cretaceous passed away for ever the two dominant races of the Mesozoic, the great reptiles and the ammonites. The belemnites dwindled to a meagre representation in the Eocene; the cycads and conifers yielded to the true flowering plants; and the familiar fish with thin, flexible scales replaced in large part the more archaic fish of the Mesozoic era. Of still greater interest and importance is the advent and subsequent reign of the true mammals: on this account the Tertiary is known, beyond all other designations, as the *Age of Mammals.*

Plants. As already stated, the plant life of the Tertiary is essentially that of the present day. While it is questionable if any species of Tertiary plant is still in existence, many of the extant genera lived in the Eocene and their number was gradually increased as Tertiary time went on.

The Miocene witnessed a remarkable distribution of tropical and sub-tropical plants into a latitude more polar than their present habitat. Forests flourished as far north as Lat. 81° 45′ in Greenland and Lat. 78° 56′ in Spitzbergen. Coal has been actually mined in Spitzbergen.

An interesting event of possible bearing on the development of the mammals was the introduction of grasses in the Miocene.

Invertebrates. The invertebrate life of the Tertiary is essentially that of the present. A few species of the Eocene are still in existence, and the number of living forms gradually increased with the passage of Tertiary time. Marine invertebrates are rare in Canada: the chief locality is Graham island, the northern island of the Queen Charlotte group. Freshwater molluscs belonging to a limited number of species are common in certain layers of the Paskapoo and Estevan formations of the plains. Species of *Unio* and *Viviparus* are particularly abundant.

Fish. The general character of the fish fauna has already

been indicated. The Canadian Tertiary rocks have not yielded many remains of fish: species of *Amyzon* have been found in the Oligocene, Tranquille, and Similkameen beds of the southern interior of British Columbia. *Amia* and *Amiurus* occur in the Oligocene strata of the Cypress hills.

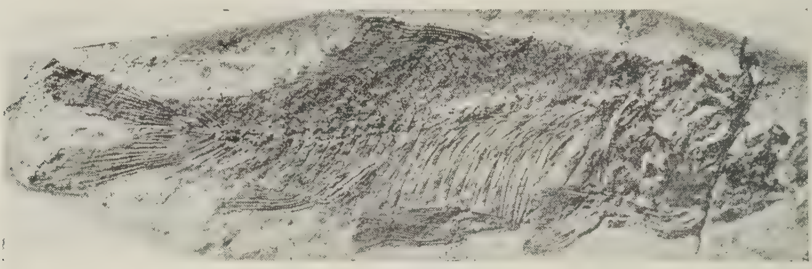

FIG. 181. CANADIAN TERTIARY FISH
Amyzon brevipinne from the Tertiary of British Columbia. About five-sixths natural size. *After Lambe.*

REPTILES. Although the great reptiles of the Mesozoic era have disappeared, essentially modern representatives of the branch are well known throughout the Tertiary. The most important feature of the reptilian life is the occurrence of extremely large turtles, *e.g.* *Trionyx*, in the Oligocene beds of the Cypress hills.

BIRDS. Birds probably existed throughout the Tertiary in much greater number than the positive evidence of remains would indicate. The life habits of birds are not favourable to preservation. Only one skeleton has been found in Canada—in the Puget Eocene beds of British Columbia. Tertiary birds were toothless like those of the present.

TERTIARY MAMMALS

It has already been pointed out that mammals possibly originated from theriodont reptiles in the Triassic. Throughout the succeeding periods of the Mesozoic the evolution of the new type was very slight; as far as known, no mammals existed except a few small forms belonging to the lowest orders, in which the young are reproduced from eggs or are born immature and carried in a brood pouch.

At the very base of the Tertiary appeared the first eutherian or placental mammals, in which the young is nourished by the mother's blood during the period of gestation and is born in a

condition which permits independent existence. This class of organism dominates the world to-day, and the history of its development through Tertiary and Quaternary time is not surpassed in interest by any other chapter of the geological story.

Before proceeding to an account of the development of the mammals in the Tertiary, it will be necessary to point out in the briefest manner the basis on which existing eutherian mammals are classified.

In all, nine orders of mammals are recognised: of these, three are of much greater importance than the others from the geological point of view.

The *ungulates* are the hoofed animals. Their teeth are adapted to the eating of vegetable food. Although they are, in some cases, provided with weapons of defence, their usual mode of protection is by flight. Many sub-orders of ungulates, of which some are entirely extinct, are known to science. Of the present-day ungulates, the chief sub-orders are the elephants, the odd-toed types, and the even-toed types.

The elephants, or *Proboscidea*, are characterised by having five toes on each foot, by the peculiar teeth, and by the possession of a trunk or proboscis, whence their name.

The odd-toed ungulates, or *Perissodactyla*, include the tapirs, rhinoceroses, and horses, in all of which the axis of the foot passes through the middle toe. In all forms, living and extinct, there is a tendency, more or less marked, for the central toe, particularly in the hind foot, to exceed the others in size and importance.

The even-toed ungulates, or *Artiodactyla*, include the sheep, cattle, deer, swine, etc., in which the axis of the foot passes between the toes, which are usually two in number.

The *carnivores* are the predaceous, flesh-eating mammals, in which the teeth are adapted to the seizing of prey and the tearing of flesh. The lion, tiger, bear, dog, etc., are typical carnivores.

The *primates* include man, gorillas, monkeys and lemurs. All these animals have a superior intelligence and a more or less erect posture.

The remaining six orders of mammals of less importance from the present point of view are the *insectivores* (shrews

and moles), *chiroptera* (bats), *edentates* (anteaters, armadillos, and sloths), *cetaceans* (whales, dolphins, porpoises), *sirenians* (manatees and dugongs), and *rodents* (mice, hares, beavers, etc.).

At the beginning of the Tertiary, in the Paleocene epoch, there existed a number of small mammals not differing greatly from the primitive types of the Mesozoic. With these there appeared for the first time true eutherian mammals, of which *Phenacodus* is the best known example. This creature is worthy of especial attention as indicative of those general characteristics, the modification and specialisation of which have resulted in all the diverse races of placental mammals now inhabiting the globe.

FIG. 182. PRIMITIVE BASAL EOCENE MAMMAL
Phenacodus primævus. After Cope.

Phenacodus was a small creature about the size of a greyhound, with a skeleton of very general structure, *i.e.* the various organs were not specialised for particular functions. Its teeth were small and low-crowned, ill adapted for either the crushing of grass or the tearing of flesh; it had five fingers and five toes, the extremities of which were armed with structures which could not be called nails, claws, or hoofs; its brain case was small and smooth, and the brain was without the corrugations seen in all the higher mammals; there were two bones in the lower joints of all legs; and the bones of the two rows of the wrist and ankle were set opposite one another, not alternating as in the higher mammals.

From such general and unspecialised animals as this there developed throughout the Cenozoic the widely diversified

animals which we know at the present time, and also a number of races which have become extinct without leaving any descendants.

Very soon, perhaps at the very beginning, the distinction between ungulates and carnivores appeared, for some of the Phenacodus-like creatures were slightly more ungulate than carnivore-like, while others were slightly more like carnivores in the structure of the teeth and toes. Before the close of the Eocene the amount of differentiation was enormous. Different races of ungulates evolved and became extinct; the differentiation of even-toed and odd-toed ungulates was completed; primitive carnivores appeared; insectivores, bats, lemurs, monkeys, and even whales, had branched off from the parent stem. We may go further and state that more intensive evolution was effected, and that horses, rhinoceroses, tapirs, pigs, etc., had been evolved. While it is doubtless true that forms ancestral to these creatures had appeared, it must be remembered that they were archaic forms and would scarcely be called horses, tapirs, etc., in the modern acceptation of these names.

The Oligocene and Miocene were characterised by the survival of some of the Eocene types, by the development of races which did not survive the epoch, and by the decidedly more modern aspect of the creatures from which the present-day mammals descended. Mammals existed which can with certainty be ascribed to existing families and which can confidently be regarded as the direct ancestors of living forms. For the most part, however, evolution had not proceeded to the degree of producing modern genera. Undoubted deer existed, but not the modern genus *Cervus*; horses were present, but not the modern genus *Equus*, etc. On the other hand, the numerous rhinoceroses were so like the existing forms that they are ascribed to the genus *Rhinoceros*.

The Pliocene is characterised particularly by the development of modern genera and the occurrence of some remarkable edentates. *Equus*, *Felis*, *Ursus*, *Castor*, *Cervus*, and *Bos* are among the Pliocene genera: that is to say, horses, cats, bears, beavers, deer, and cattle existed. It is to be understood, however, that none of the modern species arose until long after the close of Pliocene time.

The above very general summary of the development of the Tertiary mammals will be supplemented by a description of a few of the important extinct groups and by an account of the life history of some existing types of mammals.

Extinct Groups of Tertiary Mammals. *The Blunt-toed Ungulates.* Very characteristic of Middle and Upper Eocene time was a group of ungulates which in some cases reached the dimensions of an elephant. They were heavily constructed and retained in general the simplicity of structure shown by Phenacodus. The primitive five toes were retained, but the terminal bone of each digit was expanded into a blunt structure which is very characteristic. *Dinoceras* and *Uintatherium* are well-known American examples.

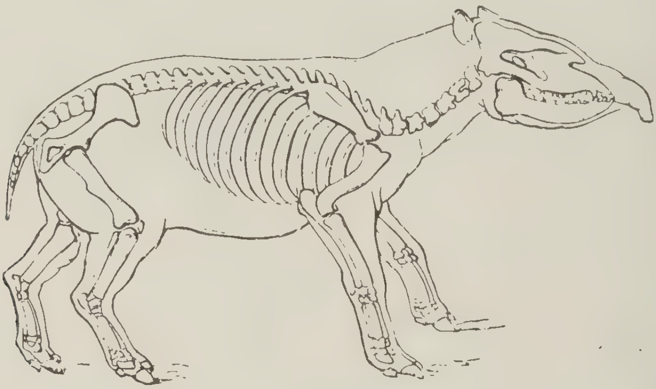

FIG. 183
Palæotherium magnum, a primitive ungulate of the Upper Eocene. Greatly reduced. *After Cuvier.*

The Titanotheres. Beginning in the Eocene and becoming extinct in the Miocene is a remarkable group of odd-toed ungulates known as *titanotheres*, some of which rivalled the elephant in size, and are to be included among the more important Miocene fossils. These great creatures are not blunt-toed like Dinoceras, but the primitive five toes have become reduced to four in the front foot and to three in the hind foot. The teeth are more specialised, with a characteristic W-shaped cutting edge on the outside of the molars. *Titanotherium* from the Miocene of Dakota is the best known example.

The Palæotheres. These animals were very important in the Upper Eocene: they belong to the odd-toed ungulates, and are regarded as ancestral to both horses and rhinoceroses.

The dentition resembles that of the titanotheres, and the toes have been reduced to three on both front and hind foot.

The Elotheres. This group of pig-like animals was very abundant in the Miocene. The feet show the even-toed structure and a high degree of specialisation in that they are already reduced to two on each foot.

The Oreodonts. Under this name is included a group of slender, even-toed ungulates of the Miocene: they have four functional toes on each foot, and a very long tail—*Oreodon, Agriochœrus.*

The Creodonts. This name is given to the most primitive type of carnivorous mammal, which began in the Lower Eocene and survived into the Middle Miocene. The earliest creodonts are scarcely to be distinguished from the contemporary ungulates, but the later forms are most distinctly carnivorous and pass insensibly into the true carnivores. *Mesonyx* and *Hyænodon* from the Eocene of America are the best examples.

THE DEVELOPMENT OF TYPICAL RACES OF MODERN MAMMALS. *The Horse.* Our knowledge of the development of mammalian life in the Tertiary is best understood and is best illustrated in the case of those creatures which culminated in the modern horse.

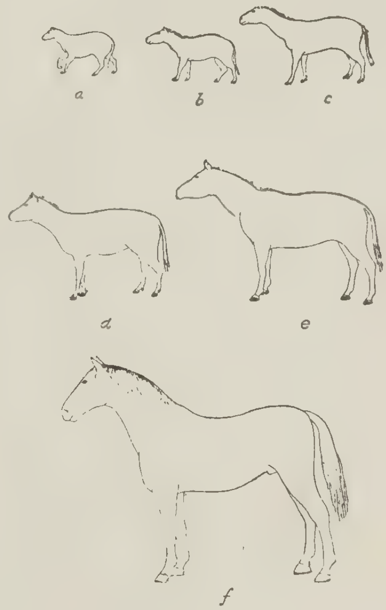

FIG. 184. THE EVOLUTION OF THE HORSE

(*a*) *Protorohippus*, Eocene; (*b*) *Orohippus*, Eocene; (*c*) *Mesohippus*, Oligocene; (*d*) *Merychippus*, Miocene; (*e*) *Pliohippus*, Pliocene; (*f*) *Equus*, Recent. *R. S. Lull*, "*The Evolution of the Horse Family.*"

Early in the Eocene, not long after the reign of the five-toed *Phenacodus*, appeared a small animal, *Hyracotherium*, not much more than two feet in length. This little creature had very simple teeth, but more specialised than those of *Phenacodus*, and the five toes had been reduced to four in the front foot and three in the hind foot, with a splint representing the fifth toe. The animal is not a horse, but it is distinctly an odd-toed ungulate and is confidently believed to be ancestral to the present-day horse.

Before the close of the Eocene appeared *Protorohippus*, a palæothere, in which the splints have gone, the teeth become deeper, and the small bone of the lower leg somewhat reduced.

Mesohippus, also a palæothere, is characteristic of Oligocene time: it is larger and has three functional toes on each foot with a splint on the front foot only.

In the Miocene the typical animal of this line of descent had become so horse-like that it is included in the family *Equidæ*. *Protohippus* is larger than its predecessors, the teeth are much

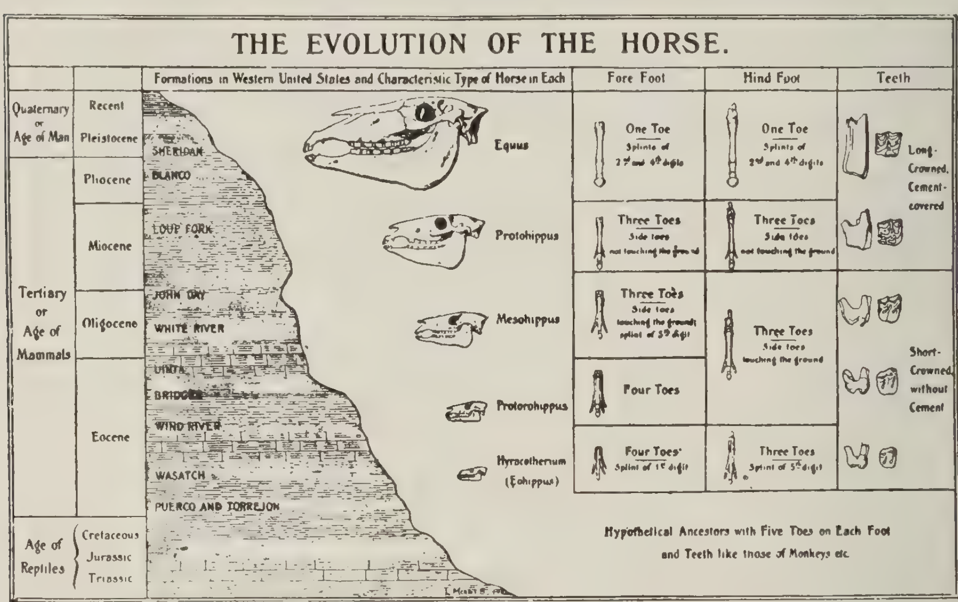

FIG. 185. THE EVOLUTION OF THE HORSE
After Osborne.

deeper, the smaller bone of the lower limb is still further reduced, and the two outer toes are not functional, *i.e.* they do not touch the ground.

Before the close of the Pliocene the genus *Equus* had evolved. Only one toe is functional, and the two outer toes are reduced to mere splints; the teeth are deep with complicated folds of enamel; and the small bone of the lower limb has dwindled and fused with the larger bone to make one rigid element.

The above example illustrates the transition of a small marsh-dwelling creature, living upon soft vegetation, to an animal capable of rapid motion on the open plains and of sustaining life by eating hard and dry grasses. Naturally, the

changes are best seen in those organs which come in contact with external objects—the teeth and feet.

The Elephant. In this case the ancestral creatures did not wander out on the plains and develop habits of flight, and in consequence the toes and the bones of the lower joint of the limbs have remained primitive to the present day. On the other hand, the whole effect of specialisation and adaptation is shown in the head structures—the teeth, tusks and trunk. As far back as the Middle Eocene appeared an animal, *Mœritherium,* which shows primitive elephantine characteristics. It had a short flexible proboscis and the outer incisors in the upper jaw were extended into short tusks, while the corresponding teeth of the lower jaw were directed outwards.

FIG. 186. THE EVOLUTION OF THE ELEPHANT FAMILY DURING THE TERTIARY

(*a*) *Elephas*, Pleistocene; (*b*) *Mammut*, Pleistocene; (*c*) *Tetrabelodon*, Miocene; (*d*) *Palæomastodon*, Oligocene; (*e*) *Mœritherium*, Eocene. *After R. S. Lull, from "Guide to Peabody Museum, Yale University."*

Between this simple form and the modern elephant many transitions are known. At first the chin elongates and results in forms with four tusks; later it retracts and the tusks of the upper jaw become very large coincident with an increase in the size of the trunk. There is a steady progression in the adaptation of the teeth, with a tendency towards a greater number of transverse rows of cusps. Finally, when the rows of cusps have become very narrow, the space between them is filled in with a secondary deposit, the cement.

Four-tusked proboscideans were common in the Miocene and also a remarkable form, *Dinotherium,* in which the lower jaw was curved downwards and a pair of downwardly-directed tusks inserted in its extremity. *Mastodon,* a large elephant-like creature, ranged from the Miocene almost into the Recent: it differs from the elephant in that the teeth show fewer rows of cusps, usually only three or four, and there is

no cement. *Elephas* itself is represented by extinct species in the Pliocene.

The Carnivores. The record of carnivorous mammals is not so complete as that of the ungulates, nevertheless there is evidence of the appearance of true carnivores in the Upper Eocene. These early forms are remarkably dog-like, and later forms show transitional stages between the various groups of living carnivores. The most remarkable fossil carnivores are the *Nimravidæ,* a family of ferocious, tiger-like creatures of great size. *Numravus* and *Machærodus* were armed with enormous tusk-like canine teeth: the former belongs to the Miocene, and the latter extends from the Miocene into the Post-pliocene.

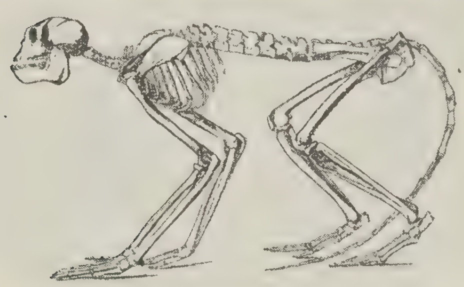

FIG. 187. MIOCENE APE
Mesopithecus pentelicus, from the Upper Miocene of Pikermi, near Athens. *After Gaudry.*

The Primates. This high group of mammals is thought to have developed from insectivores. The lower forms (lemurs) are known from Eocene deposits of both Europe and America, but they are not known in these continents after the beginning of the Miocene. At present they occur only in Madagascar and in parts of Africa and southern Asia.

The true apes appear in the Middle Miocene. The best known form is *Mesopithecus* from Lower Pliocene strata near Athens.

CHAPTER XVII

THE QUATERNARY PERIOD—THE PLEISTOCENE EPOCH

The Pleistocene, or "most recent" time, comprises the latter part of the Cenozoic, extending from the close of the Pliocene to the Recent. The period term, Quaternary, a remnant of an early classification, is practically synonymous.

The beginning of this time is well marked in many northern and far southern regions by the on-coming of the Ice Age; but beyond the limits of glaciation the division between the Pliocene and the Pleistocene is much less certain. The end of the Pleistocene is quite indefinite since no important change of conditions separates it from recent times. In early American works on geology the Quaternary is divided into three periods as follows:

Quaternary
- 3. Recent period. Elevation, existing conditions, with species of animals still living.
- 2. Champlain period. Depression of the land and invasion of the sea.
- 1. Glacial period. Elevation and great ice sheets.

THE GLACIAL PERIOD[1]

In the earlier days of the science, the Glacial period was thought of as a unit and was considered as of comparatively short duration. Later work has shown that the Glacial period was really of enormous length as compared with the other two and was broken by warm intervals, *Interglacial periods*, lasting many thousands of years, each probably of much more

[1] The use of the word "period" for these divisions is sanctioned by custom; they are not periods in the stricter sense of the term.

importance than the Champlain and Recent periods combined. The most complete classification of the formations of the Glacial period has been made in Iowa and adjacent states, where the deposits of the different ice advances and the interglacial beds are best displayed: it is as follows:

Post-glacial time.
Wisconsin ice advance.
  Peorian interglacial stage.
Iowan ice advance.
  Sangamon interglacial stage.
Illinoian ice advance.
  Yarmouth interglacial stage.
Kansan ice advance.
  Aftonian interglacial stage.
Nebraskan (Pre-Kansan or Albertan) ice advance.

Conditions during the Pleistocene in North America were very unstable, with Arctic climates interchanging with temperate climates. It is probable that these changes affected the whole continent and very likely the whole world; although in what are now warm temperate and tropical regions the cooling down was not great enough to produce ice sheets except on high mountains.

The succession of events recorded in the central United States no doubt extended into Canada also, but later ice advances over a given region usually destroy the evidence of earlier ones, so that only the effects of the last, or Wisconsin, ice advance are widely shown. One great interglacial interval with a warmer climate than the present is splendidly displayed at Toronto and also in the Moose River region, and evidences of interglacial times occur in Manitoba, Alberta, and British Columbia.

EXTENT OF GLACIATION IN NORTH AMERICA

So far as known, glaciation on our continent began in the Rocky Mountain or *Cordilleran* region, where small mountain glaciers expanded as the climate grew colder at the end of the Pliocene and coalesced into great valley glaciers, burying much of British Columbia and the mountainous part

of Alberta, except the higher peaks, which projected as "nunataks" above the fields of snow.

Next, as shown by J. B. Tyrrell, ice accumulated west of Hudson bay in the *Keewatin* region. Here the ice formed on

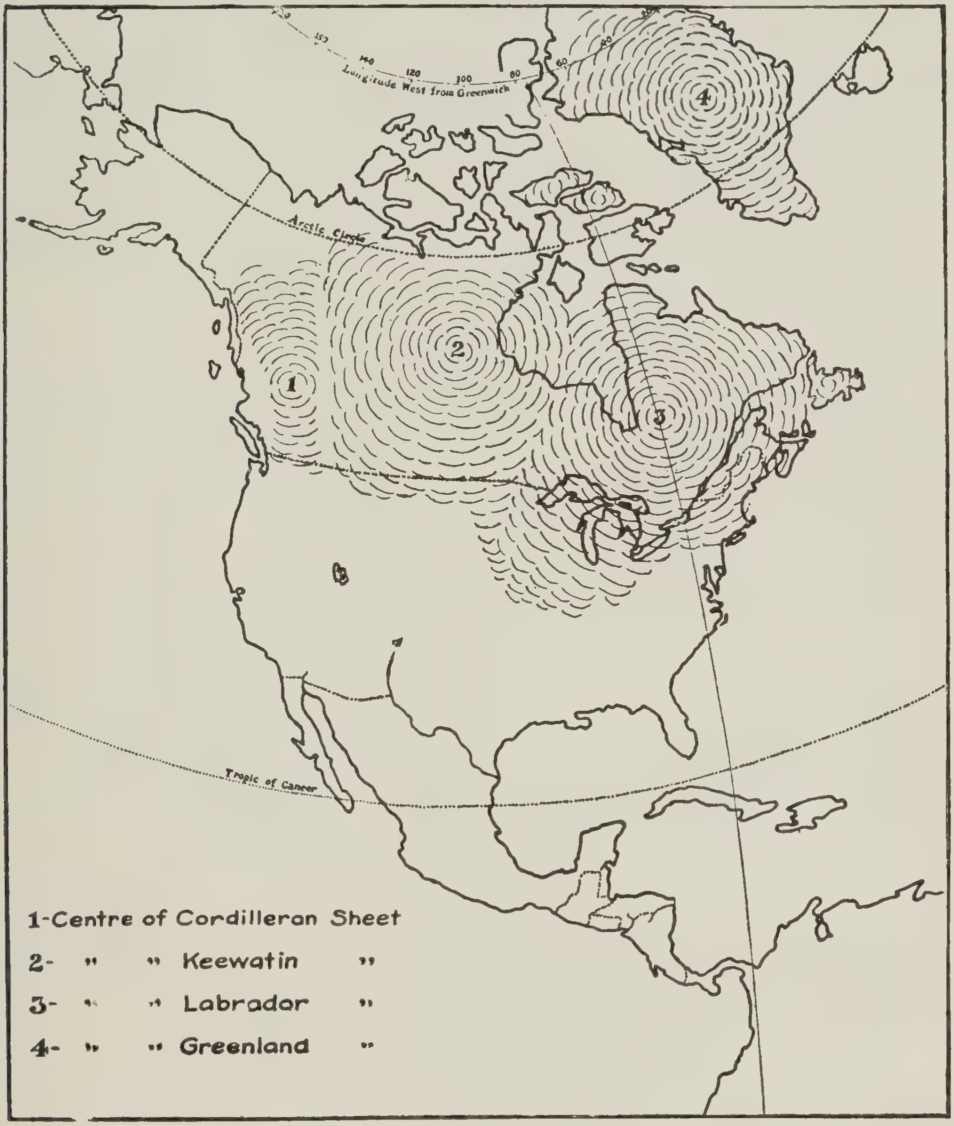

FIG. 188. GLACIAL MAP OF NORTH AMERICA

low ground, averaging not more than 1500 feet above the sea at present, and expanded to a vast sheet which reached the Rockies on the south-west and advanced as far south-east as Cincinnati in Lat. 38° N. It seems also to have occupied much of the bed of Hudson bay. It carried Pre-cambrian

boulders 800 miles from the Keewatin region to the foothills of the Rockies, leaving them at elevations 2000 or 3000 feet above their starting-point. An uphill motion of ice sheets may be accounted for by the great thickness of ice at the centre, so that the surface has an opposite gradient. It is the slope of the upper and not of the under surface of the sheet which determines the motion. Similar upgrade movements of ice sheets are known in other countries, *e.g.* in Sweden, where boulders were transported across the mountains on the Norwegian border.

Mr. Tyrrell has shown that at one time in the Pleistocene a comparatively small glacial centre existed in north-western Ontario, forming the *Patrician* ice sheet, but this was merged in the larger neighbouring sheets at the time of their greatest extension.

The *Labradorean* ice sheet began east of James bay in Lat. 52° N., as shown by Low, and covered nearly all of eastern Canada and a considerable part of the northern states. It was this ice sheet which covered southern Ontario; and it appears to have passed right over the Adirondack mountains, which reach a height of 5000 feet, so that its thickness to the north may have been 10,000 or even 15,000 feet.

The *Greenland* ice sheet may be mentioned to complete the series. When this great island was first glaciated is not known, but it is still in the Ice Age, though a fringe of coast is free from snow in the summer.

The whole area covered with ice at one time or another was about 4,000,000 square miles, its southern edge running roughly a degree south of the boundary of British Columbia, then following the Missouri south-east to the Mississippi, then the Ohio north-east, and finally bending a little south of east and ending at New York City.

All of Canada except the higher parts of the Cordillera, the northern part of the Yukon Territory, the Torngat highlands in north-eastern Labrador, and the Shickshock mountains of Quebec seems to have been covered with ice at some time during the Glacial period. These regions, still among the coldest in America, seem to have been left uncovered because of their small snowfall; for cold alone, without moisture for precipitation as snow, will not produce an ice sheet.

CONDITIONS DURING THE GLACIAL PERIOD

The climate during the Cenozoic underwent important variations, but for the greater part was mild even in the far north, as shown by remains of luxuriant forests in Spitzbergen and Greenland; and by the trees of Dunvegan in northern Alberta, which remind one of the southern states at present. During the Pliocene, however, the temperature fell, and while the gold-bearing gravels of the Klondike placers

FIG. 189. INTERGLACIAL BEDS (BETWEEN PARALLEL DARK LINES)
Don Valley Brickyard, Toronto, Ontario.

were being deposited in the Yukon Territory the climate seems to have been about as cold as at present, with a growth of birch and spruce trees and a splendid fauna, including elephants, horses, bears, deer, and bison.

The slowly on-coming ice blotted out all life as it advanced until Canada was glacier-covered and blizzards swept over the white plains in every month in the year. The only existing parallel to these conditions is to be seen in Greenland or the Antarctic continent.

FIG. 190. TWO BEDS OF TILL WITH STRATIFIED SAND BETWEEN

The stratified sand beneath the lower till is fossiliferous and belongs to the upper part of the Toronto formation. View at Scarboro heights, near Toronto.

INTERGLACIAL PERIODS

As shown on a former page, evidence of several interglacial periods is found in the United States and of at least one important one in Canada. In the earliest interglacial time, the *Aftonian* of Iowa, animal life included "ground sloths" like *Mylodon* and *Megalonyx*, camels, sabre-toothed tigers, as well as bears, horses, and elephants. The trees of the time seem to have been not very different from those of the present.

The best preserved interglacial beds of Canada, named the *Toronto formation*, may be of the same age or may correspond to the Yarmouth or Sangamon stage. The Toronto formation has provided much the largest number of fossils, both of plants and animals, yet found between two ice advances in the American Pleistocene. It includes freshwater shell fish of modern species; many of the clam shells now living in more southerly waters; seventy-two species of insects, all but two extinct; remains of fish, and of elephants, bison, deer, bears, and other mammals.

FIG. 191
Acer pleistocenicum, an extinct maple from the Interglacial beds, Don Valley, Toronto.

In certain beds of clay in the lower part of the formation there are many tree trunks and branches, as well as beautifully preserved leaves. More than thirty trees have been recognised, such as oak, maple, hickory, basswood, wild plum, red cedar, which can still grow in the region; and also some, like the pawpaw and osage orange, which belong to a region much farther south. Botanists believe that the climate was several degrees warmer than at present, like that of Ohio or

Pennsylvania. There is evidence to show that the Toronto interglacial interval lasted for 75,000 or 100,000 years.

The beds of lignite between two boulder clays near Moose river, 350 miles north, which include large trees and indicate a long and mild interglacial stage, were probably formed at the same time, proving that the Labrador ice sheet had completely vanished.

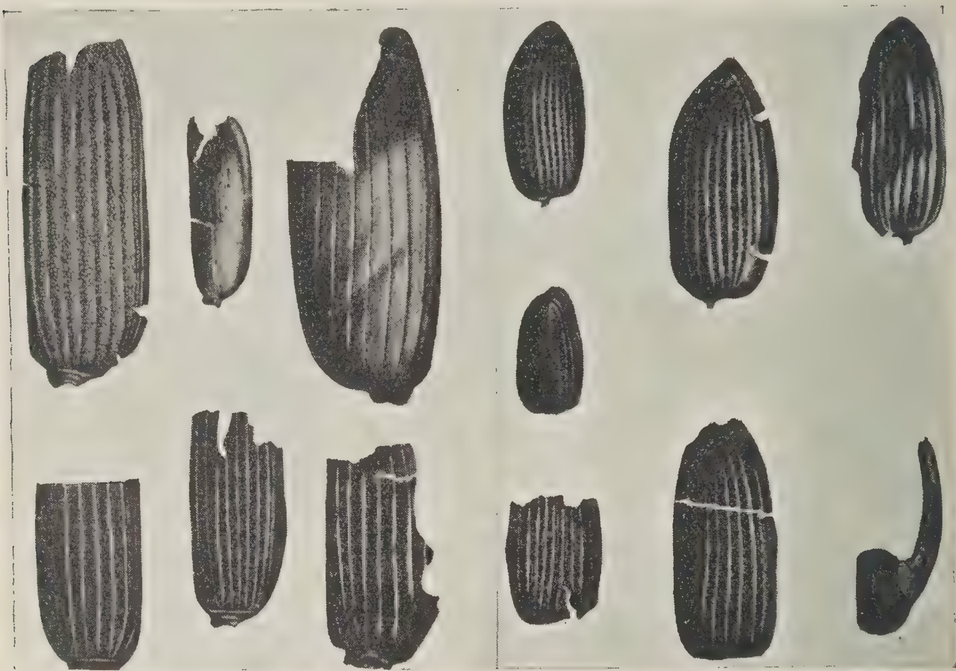

FIG. 192. EXTINCT BEETLES
From Interglacial beds, Scarboro heights, Toronto.

There are interglacial beds at Rolling river in Manitoba, Rosebud creek and Belly river in Alberta, and at some points in British Columbia; but it is uncertain whether they are of the same age as the beds described from Ontario.

THE WITHDRAWAL OF THE ICE SHEETS AND THE FORMATION OF GLACIAL LAKES

After each glacial stage had reached its climax the warming up of the climate caused the ice sheets to retreat slowly in the opposite direction from their advance. The centres of the Keewatin and Labrador ice sheets are so placed that the most important drainage systems of Canada would be blocked by their advance and set free gradually on their retreat. As a

consequence, the waters of these river basins must have been ponded back into great lakes during the on-coming of the ice, and similar lakes must have formed in front of the ice as it withdrew. The series of glacial lakes following up the Wisconsin ice sheets when they began to wane has been carefully studied in some places, and the lakes thus formed have left important effects in the central provinces of Canada.

The fertile soils of Edmonton and Calgary seem to have been formed by the silt of great glacial lakes, though their boundaries and outlets have not yet been worked out. *Lake*

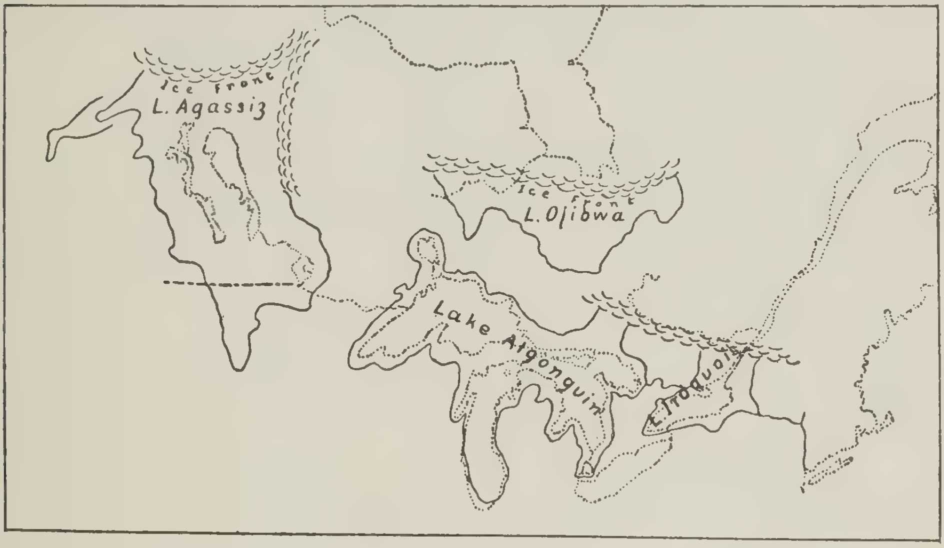

FIG. 193. SKETCH MAP OF POST-GLACIAL LAKES

Agassiz occupied parts of Saskatchewan, Manitoba, western Ontario, North Dakota, and Minnesota, and probably covered more than 100,000 square miles—more than three times the area of Lake Superior. As the present outlet for the southern prairie waters through Nelson river to Hudson bay was ice-covered, the great basin spilled southwards by the Red River valley and reached the Mississippi, which must have been greatly swollen at that time. The old beaches of Lake Agassiz are plainly to be seen, and the finer deposits off shore make some of the flattest and most fertile prairies, as near Winnipeg. The final separation of the Keewatin and Labrador or Patricia ice sheets permitted the waters to flow north-east, but remnants of Lake Agassiz still remain, forming Lake Winnipeg and others of the Manitoba lakes.

While Lake Agassiz still existed the basins of the Great Lakes began to be set free by the thawing of lobes of the Labrador ice sheet, and at length those of Superior, Michigan, and Huron united to form *Lake Algonquin*, almost as large as Agassiz and very much deeper. It had several outlets at different times, first probably past Chicago into the Mississippi, then over Niagara Falls, then by the Trent valley, and finally once more over Niagara Falls. For most of its existence the outlet was into *Lake Iroquois*, which occupied the Ontario basin and drained past Rome, N.Y., into the Hudson.

The shore cliffs and beaches of Lakes Algonquin and Iroquois are almost as perfect as those of the present lakes, but usually stand much higher up and are no longer horizontal. They have undergone "differential elevation," and rise as one advances in a direction of N. 20° E. The land in that quarter sank beneath its immense load of ice and then rose again as the load was removed by the melting of the ice sheets, deforming the once horizontal beaches.

Another glacial lake, called *Lake Ojibway*, but less perfectly known, deposited the great belt of clay north of the Hudson Bay watershed in Ontario and Quebec.

These vanished lakes have left us fertile soils and well-drained sites for railroads and cities, as well as supplies of sand and gravel useful for many purposes.

THE MARINE EPISODE OR CHAMPLAIN PERIOD

It has just been shown that the northern part of the continent was depressed by the sheets of ice which gathered upon it in the glacial periods. As the ice withdrew, all the land below a certain level was flooded by the sea in what has been called the *Champlain period*, because its effects are well shown near Lake Champlain. Marine beaches are found from New York northwards, ascending as one advances and reaching a maximum of 690 feet above present sea level at Kingsmere in the Ottawa valley. Marine beaches are found on Mount Royal at 620 feet, and occur hundreds of feet above the sea along the lower St. Lawrence and on the shores of Labrador.

To the north-east in Labrador they grow lower, reaching only 225 feet at the most northerly point studied. Around Hudson bay raised beaches are found up to 450 feet.

In many of the beach deposits there are sea shells belonging to species now living in nearby waters, and remains of whales, porpoises, and seals have been found in eastern Ontario. Sea shells are found as far west as Brockville, but not around the shores of Lake Ontario, though the basin must have been far below sea level. Probably the Niagara river kept the waters fresh.

Marine deposits are found up to about 350 feet along the shores of British Columbia also, and shell beds occur in Stanley Park, Vancouver, and at Nanaimo, as well as elsewhere in the province.

With the waning and final disappearance of the ice sheets, the depressed portions of the country rose and slowly reached their present level.

PHYSIOGRAPHIC EFFECT OF THE GLACIAL PERIOD

At the end of the Pliocene it is probable that Canada was deeply mantled with the products of millions of years of weathering; that most of the rivers had mature valleys; and that lakes were infrequent. After the final retreat of the Wisconsin ice sheet the country was left in a totally different condition, the central areas of glaciation having been scoured to the bare solid rock, and the debris having been spread as boulder clay or piled as crescent-shaped moraines over the region to the south. As a result, basins were excavated in the rock or made by the dumping of glacial debris across valleys. In this way innumerable lakes were formed, so that Canada probably has as many lakes as all the rest of the world; and the drainage was completely disorganised, rivers flowing at haphazard wherever the slope of the drift deposits permitted. Thus it is that Canada presents physiographically so very youthful an aspect, almost every river having lakes threaded on its course and tumbling at one point or another over rocky obstructions causing rapids or falls. The youthful condition

of the drainage provides lakes great and small for navigation, and waterfalls of all dimensions for power.

The rock flour of the wide-spread sheets of boulder clay is generally rich in lime, potash, and phosphorus, the essential mineral ingredients of a good soil, unlike the profoundly leached residual soils south of the glaciated region. On the other hand, the central areas of glaciation are largely bare rock and useless except for their mineral contents.

FIG. 194

Restoration of the mastodon, *Mammut americanum*, by G. M. Gleason from a painting in the National Museum, Washington.

THE PLEISTOCENE IN OTHER REGIONS

South of the glaciated area just described, beds of sand and gravel were formed and rock weathering continued, but the results are much less marked. In South America, glaciers descended 1000 metres or more below the present level of snow on the Andes, and Patagonia was covered by an ice sheet. Two ice advances with an interglacial period have been found.

Next to North America Europe was the continent most affected by the Glacial period, and ice covered about 2,000,000

square miles, reaching Lat. 52° N. on low land, while the Alpine glaciers descended far below the present level. European geologists describe four great ice advances in the Alps, separated by three interglacial periods. Just how these subdivisions correspond with those recognised in America is not certain.

It is interesting to find that Siberia, the coldest part of the earth's surface, like our Klondike region, was not glaciated on a large scale, though the mountain glaciers of the Himalayas to the south reached thousands of feet lower down than at present. In Africa and Australia the effects of the Glacial period are found only on the highest mountains.

THE LIFE OF THE PLEISTOCENE

Mammals seem to have reached their highest point in variety, numbers, and size in the Pleistocene. In North America, ground sloths and elephants (mammoths and mastodons) survived all the ice advances, which might have been expected to destroy such large, plant-feeding animals, and then perished by some unknown cause as the climate grew milder. Horses, camels, tapirs, and the sabre-toothed tiger perished earlier.

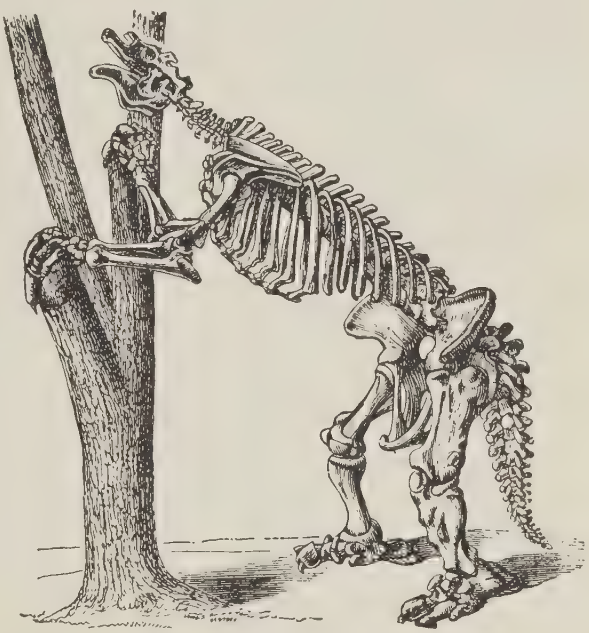

FIG. 195
The great ground sloth of the Pleistocene, *Megatherium americanum.* About one-eightieth natural size. *After Zittel.*

In Europe many animals now thought of as African, such as the mammoth (elephant), woolly rhinoceros, hippopotamus, and lion, survived until the middle of the Glacial period, and even reached England, then joined by land to the Continent.

In South America the gigantic ground sloths, *Mylodon, Megatherium,* etc., which pulled down or dug up small trees to feed on their foliage, passed away toward the end of the Pleistocene, leaving only the small, present-day sloth hanging beneath the branches in Brazilian forests as a survivor, and the huge *Glyptodon* with a shell of bony plates is succeeded by the little burrowing armadillo.

In Australia there were giant marsupials, *e.g. Diprotodon,* which have left only diminutive descendants; and in New

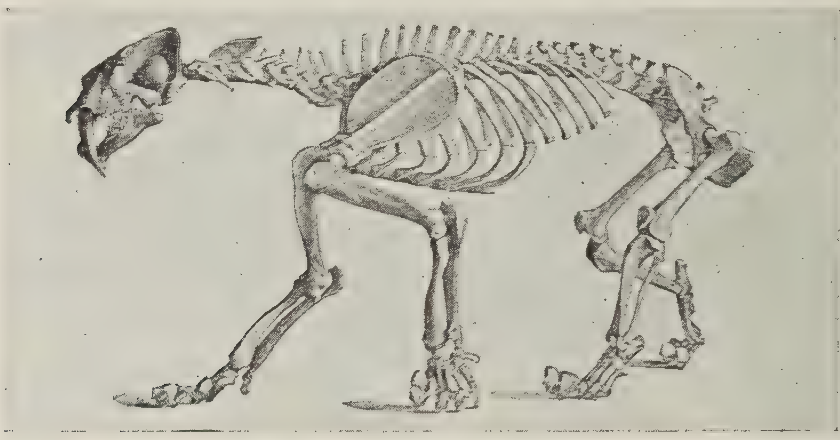

FIG. 196. PLEISTOCENE CARNIVORE
Machærodus neogæus, from the Pleistocene of Argentina. Reduced. *After Burmeister.*

Zealand and Madagascar there were huge running birds without the power of flight, *Dinornis* and *Æpyornis,* larger than the ostrich, which have left no descendants in the latter island, and only the little apteryx in New Zealand.

Africa, and to a less extent Asia, are the only continents which have preserved their mammal fauna to a large degree, and these two continents were comparatively little affected by glacial action.

Plants and the lower animals, with the exception of insects, seem to have undergone little change during the Pleistocene.

MAN'S APPEARANCE IN GEOLOGY

The most important of the mammals—man—remains to be considered. That he is closely related to the higher apes is shown by the fact that almost every human bone and muscle

has its counterpart in a gorilla or chimpanzee, the chief differences being the adaptation of the hind limbs to walking upright, the development of the thumb and fingers of the hand, and the much larger brain. From these facts evolutionists conclude that man and the higher apes have descended from a common ancestry.

Just where man originated is not certain, but the probabilities point to southern Asia as the place and the early

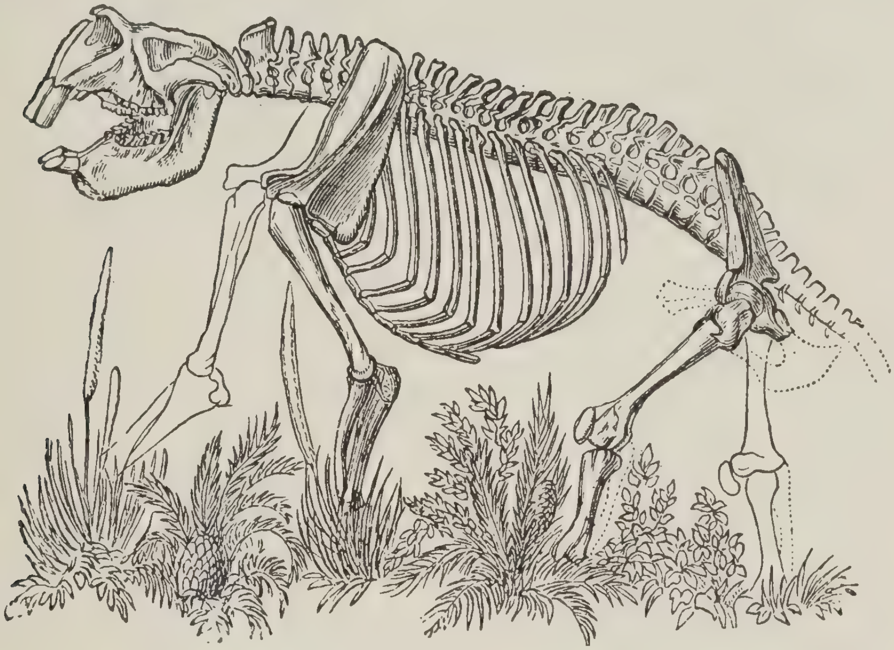

FIG. 197. PLEISTOCENE MARSUPIAL
Diprotodon australis, about one-fiftieth natural size. *After Owen.*

part of the Pleistocene as the time. At Trinil in Java about the beginning of the Pleistocene there lived, along with a number of other extinct animals, a somewhat man-like creature which has been called *Pithecanthropus erectus*. The remains include the greater part of the skull, a thigh bone and two teeth, and belonged to a creature which walked upright, had human-looking teeth, and a brain more than half as large as that of the average modern man and far larger than that of any ape. *Pithecanthropus* seems, therefore, to have been an intermediate form, as the name suggests, an ape-man.

Throughout the Cenozoic the mammals had been steadily

increasing the size of their brains, and the climax of this development of brains was reached in man himself.

There is no certain evidence of men in America before the end of the Ice Age, so that it is necessary to go to the Old World for information as to the first men. The earliest supposed proofs of their existence in Europe are the *eoliths*, rudely chipped bits of flint found in deposits belonging to the early Pleistocene or the end of the Pliocene; but some authorities doubt the human origin of these imperfect knives or scrapers and think them due to accidental fractures.

The first undoubted tools occur, apparently, near the beginning of the last interglacial time, and the finding of a few fragmentary jaws and skulls make it certain that man existed. The climate seems to have been somewhat warmer than at present, and the animals found associated with man suggest Africa, which was then connected directly with Europe, and include elephants, the rhinoceros, the hippopotamus, and the sabre-toothed tiger or lion.

Later in this interglacial period the climate grew colder and man began to take refuge in caverns instead of living in the open. Complete skeletons show that the men of the time had slightly bent knees, a receding chin, and a massive bony ridge at the eyebrows, with a very retreating forehead above. They could not have been prepossessing according to our standards, though their brains were nearly equal in size to those of modern men, and they had already made man's most fundamental discovery, the use of fire.

From the beautifully chipped flint arrowheads, knives and scrapers which they made, these men have been called *palæolithic* (ancient stone); and they seem to have been an artistic people, since they have left many sketches or even coloured pictures of the animals which they hunted. Their prey included several creatures adapted to endure a cold climate, such as the hairy mammoth and rhinoceros, the bison and, at the on-coming of the last ice advance, the musk ox and reindeer.

The Palæolithic stage was a long one; but with the recession of the last ice sheets a new race comes in, more like modern European man, and better armed, since it had learned to grind into shape stone axes and other tools, which were much

more efficient than the brittle flint tools of the earlier time. These men have been called *neolithic* (new stone); still later Europeans acquired the use of bronze and other metals, as shown by the earliest historic records, and one enters upon the field of ancient history rather than geology.

Our North American Indians, before the coming of the white man, were still in the stone age, and combined the use of chipped arrowheads, etc., like Palæolithic tools, with that of ground and polished axes like those of Neolithic times. To a slight extent they used native copper also, corresponding to the age of bronze.

The earliest hint of man in Canada is the reported finding of stone tools along with bones of the caribou at the bottom of the Iroquois gravel bar in West Toronto; which takes us back thousands of years to the time when the last ice sheet still lingered in the Thousand Island region. Unfortunately the evidence is meagre and the find was not investigated by any trained scientific observer.

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